MODERN CAMOUFLAGE TECHNIQUES

This was written as a snap requirement as part of a course and has therefore not been as exhaustive as may have been desired. The authort has tried to provide an overview of his thoughts fused with data available in books and the internet about the subject of camouflage, its techniques and their application in the realm of the modern defence forces.

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INTRODUCTION

What is Camouflage?

1. In nature, every advantage accrued to an animal increases its chances of survival, and therefore its chances of reproducing. This simple fact has caused animal species to evolve a number of special adaptations that help them find food and keep them from becoming food. One of the most widespread and varied adaptations is natural camouflage, an animal's ability to hide itself from predator and prey.[1]

Figure 1

A Cryptic Frog - This species has developed a colouring, texture and form that are similar to the leaves found in its environment.[1]

2. In war, the function of camouflage is very simple: It is used to hide yourself and your equipment from the enemy (the art of concealment by altering an object to blend with its physical surroundings and environment). People have been using camouflage in some form or another from the beginning of human civilisation. In fact, the basic idea of camouflage predates humans entirely. It comes from the natural adaptations that let animals blend in with their environment.

"Noun- Device or stratagem for concealment or deceit" [2]

3. Initially, it was only necessary to conceal an object from the visible physical surroundings. However, as technology has developed, it has become necessary to conceal an object over multiple bands of the electromagnetic spectrum. Most notably, in addition to visible concealment, it has become necessary to conceal an object's infrared radiation (IR) to prevent thermal detection systems and the like from identifying an object based on its heat signature. Technological advancements have increased the detection threat spectrum and therefore encouraged counter measures which will be discussed subsequently.

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[1] howstuffworks.com

[2] Webster's

Ambiguous Camouflage Terminologies

4. Certain terms associated with camouflage require to be defined so as to compartmentalise their application and enable correct perception.

(a) Camouflage. The method or result of concealing personnel or equipment from an enemy by making them appear to be part of the natural surroundings.

(b) Adaptive Camouflage. Adaptive camouflage is a type of defence mechanism in which an object is rendered either hard to see or invisible to a particular observer. A typical adaptive camouflage system would likely include a network of flexible electronic flat-panel display units arrayed in the form of a blanket that would cover all observable surfaces of an object that one seeks to cloak. It camouflage differs from conventional means of concealment in two important ways:-

(i) It makes the camouflaged object appear not merely similar to its surroundings, but effectively invisible through the use of mimicry.

(ii) Active camouflage changes the appearance of the object as changes occur in the background. Ideally, active camouflage mimics nearby objects as well as objects as distant as the horizon.

(c) Active Camouflage. Active camouflage has the capacity to provide perfect concealment from visual detection. It differs from adaptive camouflage in that it is real time continuous streaming. An intelligent adaptive camouflage system can be classified under this.

(d) Stealth. The use of advanced design and specialized materials to make an aircraft difficult or even impossible to detect by radar. This could also take the form of Visual, Acoustic, and IR stealth apart from radar stealth.

(e) Cloaking. A device which renders something invisible or undetectable .Operationally it is an extension of the basic technologies used by stealth aircraft, such as radar-absorbing dark paint, optical camouflage, cooling the outer surface to minimize electromagnetic emissions (usually IR) or other techniques to minimize other EM emissions, and to minimize particle emissions from the object. Alternatively, metamaterials provide the theoretical possibility of making electromagnetic radiation appear to pass freely through the 'cloaked' object.

Evolution of Camouflage in the Armed Forces

5. Land Forces Camouflage.

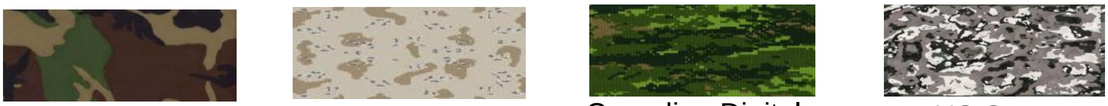
(a) Camouflage was uncommon in the early days of the First World War as military traditions concentrating on the ideal fighting spirit considered the idea of hiding from the enemy somewhat shameful. Some units actually entered the war in 1914 still clad in attention-grabbing colours, such as the French who initially wore bright red trousers and blue Greatcoats as part of the standard uniform.[3] However, the first concessions were quickly made, such as the German 'Pickelhaube' helmets being covered with cloth covers designed to prevent them from glinting in the sun.

(b) The French established a *Section de Camouflage* in 1915.[4] The experts were for the most part, painters, sculptors and theatre-set artists. Technological constraints meant patterned camouflage uniforms were not mass-produced during World War I. Each was hand-painted, and so they were restricted to snipers, forward artillery observers, and other exposed individuals. More effort was put into concealing equipment and structures.

(c) In 1927 Louis Weinberg introduced "Camouflage in Dress Design".[5] The first mass-produced military camouflage was the Italian *telo mimetico* ("mimetic cloth") pattern of 1929, used to cover a shelter-half (*telo tenda*). In 1931 it was copied and adopted by the German Army, who had been begun using camouflaged cloth in 1918 with the indigenous *Buntfarbenanstrich*. The Soviet Union issued "amoeba" disruptive-pattern suits to snipers from 1937 and all-white ZMK top-garments the following year, but it was not until hostilities began that more patterns were used. With mass-production of patterned fabrics, they became more common on individual soldiers in World War II. Initially, patterning was uncommon; a sign of elite units, to the extent that captured camouflage uniforms would be recycled by an enemy.

(d) The camouflage or disruptive pattern, as they were now referred to, saw technological advancements in material and patterns for different environments the most widely recognised as illustrated below. Vehicle camouflage will be discussed in greater detail later but its evolution was corresponding to personnel camouflage until quite recently.

Figure 2



[3] Willmott, H.P- *First World War*
[4] www.tate.org.uk/tateetc/issue4/camouflage.htm
[5] Abid

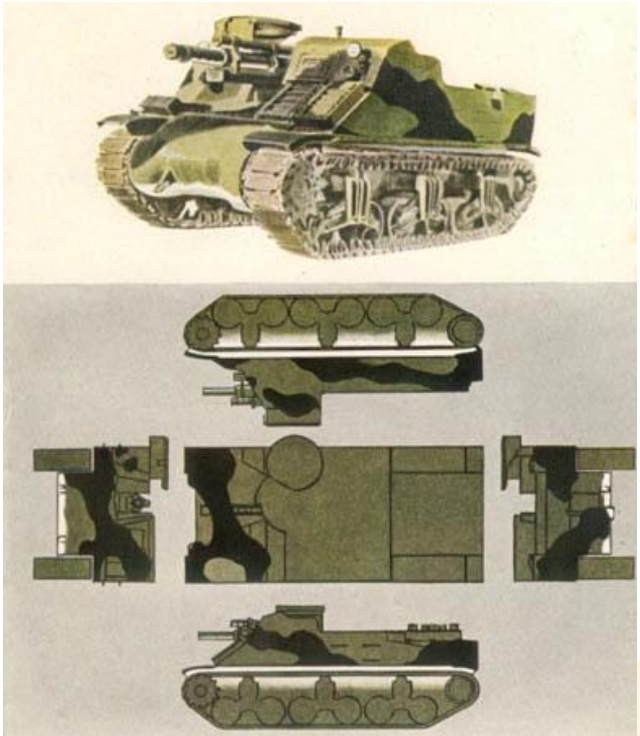
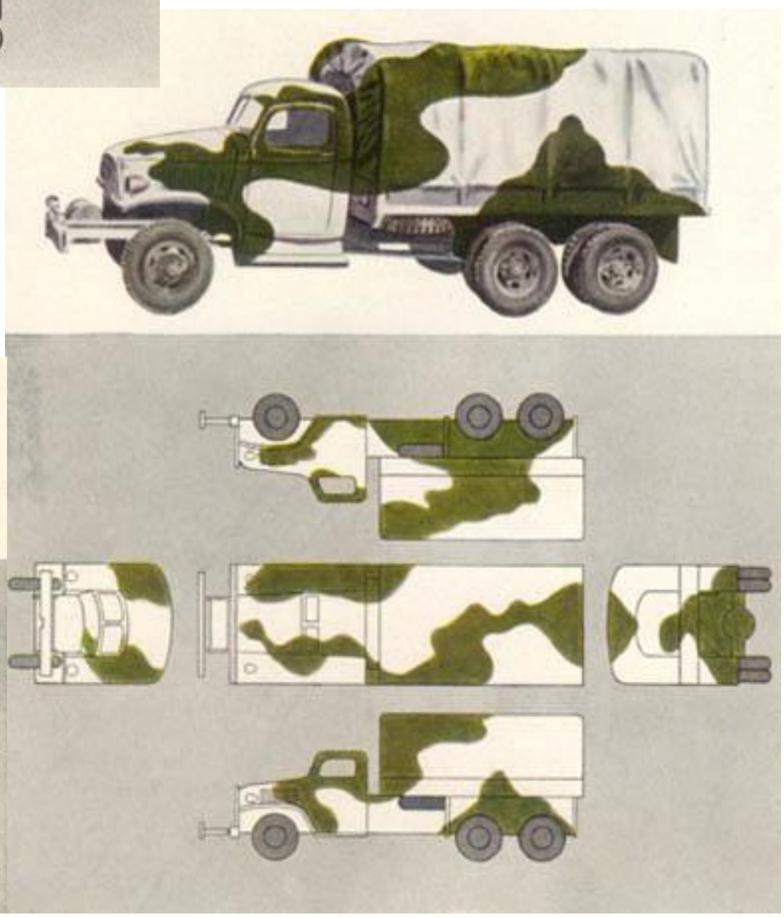


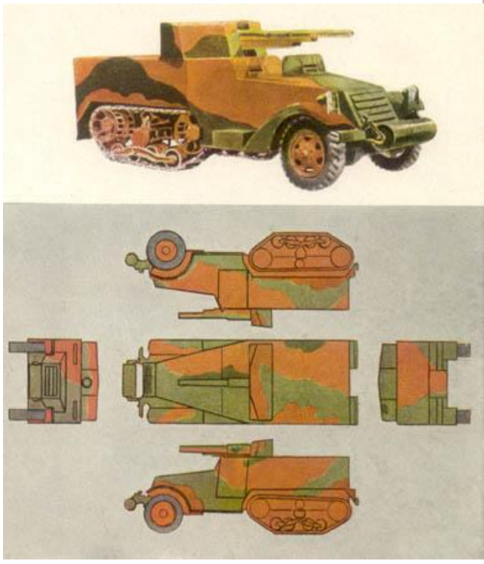
Figure 3

Disruptive Painting for

Different Terrain

(WW 2)





6. Naval Camouflage.

(a) Until the 20th century, naval weapons had a very short range, so camouflage was unimportant for ships. Paint schemes were selected on the basis of ease of maintenance or aesthetics.

(b) At the turn of the century the increasing range of naval engagements, as demonstrated by the Battle of Tsushima, prompted the introduction of the first camouflage, in the form of some solid shade of gray overall, in the hope that ships would fade into the mist.

(c) First World War. These schemes were used on merchant ships and smaller warships. Battle fleets continued to be painted in various shades of gray. Dazzle Paint (discussed subsequently) intended as an anti-submarine measure for merchant ships sailing independently grew onto naval ships.

Figure 4

USS Charles S Perry (1944)

(d) Second World War. In 1935, the US Navy Naval Research Laboratory[6] began studies and tests on low visibility camouflage to:-

(i) Reduce visibility by painting vertical surfaces to harmonize with the horizon and horizontal surfaces to blend with the sea.

(ii) Confuse identity and course by painting obtrusive patterns on vertical surfaces. Some camouflage methods served both purposes.

(e) British naval ships were generally dark gray in northern waters, and light gray in the Mediterranean or tropical waters. In the first year of the war British captains largely painted their ships as they saw fit. As the war continued, the Admiralty introduced various standardized camouflage schemes.

(f) After the Second World War, the universal adoption of radar made camouflage generally less effective. However, camouflage might have helped United States warships avoid hits from Vietnamese shore batteries using optical rangefinders.[7]

Figure 5

Royal Norwegian Navy

Splinter Camouflage

[6] Sumrall, Robert F. "Ship Camouflage (WWII): Deceptive Art"
[7] Abid

7. Aircraft Camouflage.

(a) The design of camouflage for aircraft is complicated by the fact that the appearance of the aircraft's background varies widely, depending on the location of the observer (above or below) and the nature of the background. For this reason, many military aircraft are painted light blue below (to match the sky), but blotchy, darker colours above (to match the ground). This is known as counter shading .

(b) Early attempts at stealth were made as early as World War I, the German Linke-Hofmann R.I being an example[8], the Germans also introducing a multi-coloured lozenge (Lozengetarnung) pattern intended to match the patchwork of fields that were found on the Western Front.

(c) In World War II the necessity of recognition of aircraft as friendly or hostile in an increasingly crowded sky almost negated the use of camouflage for diurnal operations, with Allied forces introducing invasion stripes during D-Day and the Luftwaffe introducing yellow Home Defence markings in the later stages of the war, with the USAAF completely abandoning camouflage in the later stages of the war.(These markings and such alike have later been applied to land forces too especially for aerial recognition).

(d) The higher speeds of modern aircraft and the reliance on radar and missiles to defend against them have reduced the value of visual camouflage, while increasing the value of electronic camouflage "stealth" measures (discussed in detail separately). Modern paint is designed to absorb the electromagnetic radiation used by radar, reducing the signature of the aircraft, and to limit the emission of IR light which is used by heat seeking missiles to detect their target (e.g. the standard grey scheme found on US aircraft).

Figure 6

US FA-18 Hornet

Ukrainian Su-25

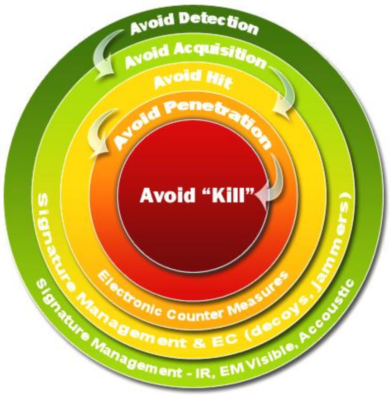
[8] Wikipedia

SIGNATURE MANAGEMENT

8. In today's complex battle-space environment, where new sensors and networked target information create a more challenging operational arena for military platforms, increased survivability demands a new more integrated approach to total signature management for low observability (LO).

9. The signature management concept has the purpose of defeating surveillance and target acquisition weapons systems that operate in the electromagnetic spectrum and the most cost-effective way to increase the probability of survival is through signature management to avoid detection. A signature is a unique signal for each vehicle, piece of equipment and personnel, to sensors operating in the electro-magnetic spectrum .

Figure 7



10. Achieving maximum platform survivability, whether for operation on land, at sea, or in the air, requires consideration of the total (multi-spectral) signature at the earliest point in the design process. It is at this stage that the cost of achieving LO is at its minimum and the ease with which it can be implemented is at a maximum.

11. The principal signatures that must be managed are increasingly multi-spectral and may include some or all of the following at differing levels of importance depending on whether the platform is designed to operate in a land, sea, or air environment.

(a) Above Water Signatures.

(i) Radar.
(ii) Infra-Red.
(iii) Radiated Noise.
(iv) Visual.
(v) Electromagnetic.
(vi) Electronic (will not be discussed).

(b) Below Water Signatures.

(i) Broadband, Narrowband & Transient Radiated Noise.
(ii) Target Echo Strength.
(iii) Ferromagnetic.
(iv) Corrosion Related Magnetic Field.
(v) DC Electric Field.
(vi) Alternating Electric & Magnetic Fields.

Factors Affecting Recognition in the Visible Region[9]

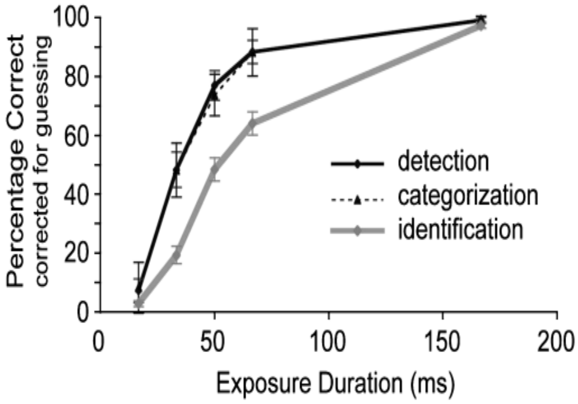
12. In the visible region, object detection/recognition/identification, to a large extent, is carried out by the sensor-the human eye unaided, or aided by an optical instrument or an electro-optical system, or through a photograph of the object.

13. Visual perception is a three stage process:-[10]

(a) Stage 1. It depends on the object, its physical properties and the background in which the object is located, the properties of light and duration of exposure.

(b) Stage 2. It is a physiological process which depends on the construction of the eye and how it forms an image of the object on the retina.

Graph 1



(c) Stage 3. It is a physiological process in which the image formed on the retina is interpreted by the brain leading to the recognition of the object. The retinal image, which is physical, is transformed into a mental image by the brain based on previous knowledge.

14. Stage 1 is the basic step and one from which emanates much of the counter measures and therefore is further elucidated as follows:-

(a) Shape and Size. Characteristics to every object; bounded by its contours with which the observer is familiar. This plays a greater role in other forms of identification (discussed later) especially with reference to its radar cross section; but even in the visible region it plays and vital role in recognition and especially against aerial reconnaissance.

Figure 8


Wrong Technique


Correct Technique

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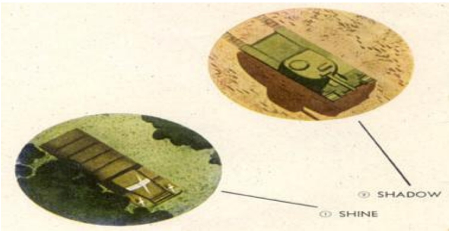
[9] JV Ramana Rao – Introduction to Camouflage and Deception
[10] Nancy Kanwisher -Visual Recognition

(b) Colour. The light reflected by an object depends on its colour. Different objects reflect different amounts and wavelengths of light energy. The contrast that is produced by differential reflection of light by various objects and its background aids in interpretation.

(c) Texture. Two objects may have the same colour, but if their optical textures are different they can be distinguished as two separate objects. The optical texture depends on the degree of smoothness and roughness. The light and shade effects are produced by texture. Texture also contributes to shine; the smoother the surface the greater the chances.

Figure 9

Figure 10



(d) Shadow. Even when an object is not clearly visible it can easily be identifiable by its shadow. This is especially useful in interpretation of aerial photographs. More so it is useful in satellite imagery comparison as to the shift of objects.

(e) Pattern. Pattern is the characteristic feature of many manmade objects and of some natural features. Individual objects in a pattern may not be discernable but if the pattern is perceived, the objects constituting the pattern can be inferred.

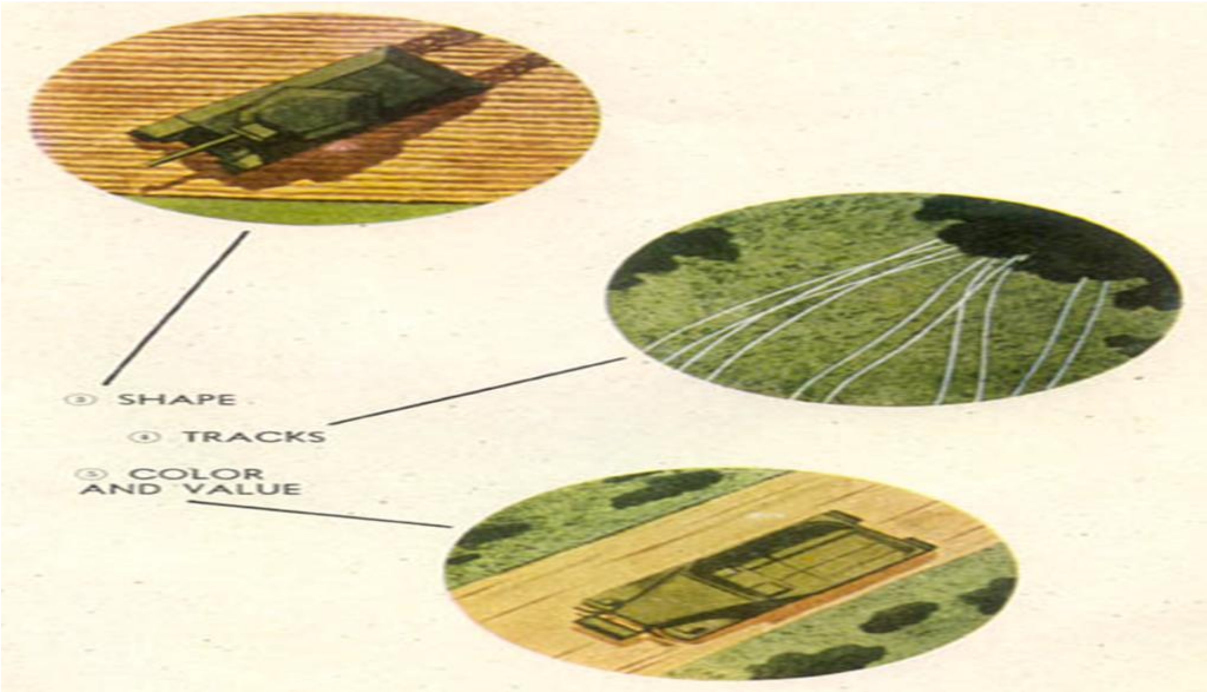
(f) Site. The knowledge of the location of the object with respect to the surrounding terrain features or other objects is helpful in object identification.

(g) Association. All solid objects are presented to the eyes as elements of colour, varying in size, shape, texture, hue and saturation, lightness or darkness. These differences enable us to distinguish on object from the other. If these differences are made to negated, one object will not be distinguishable from the other. Some objects are so commonly associated with one another that the presence of one indicates or confirms the presence of the other (e.g. Tanks are commonly associated with tracks, gun barrel etc.).

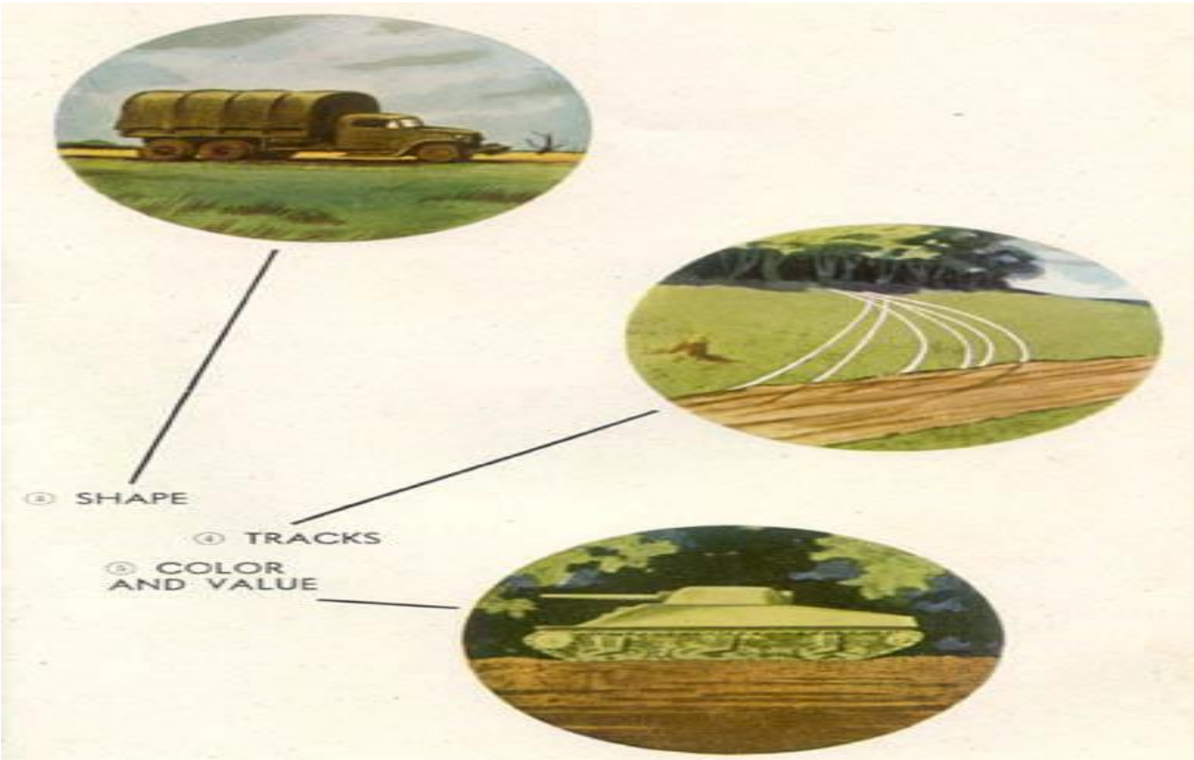
(h) Misc. Other factors like movement, noise, smoke, etc are not being discussed in detail here are their application to detection avoidance is obvious and do not directly influence camouflage techniques.

Figure 11

Figure 12



Enemy Air Observation



Enemy Ground Observation

Passive Surveillance[11]

15. Passive surveillance systems utilise electro-optical systems operating in the visible wavelength and infrared (IR) wavelength bands.

(a) They operate in the 0.4 to 0.7 micrometer portion of the electromagnetic spectrum. These systems rely on the visual, that is, that which is recognisable by the human eye. In addition, optical augmentation systems, which range from hand-held binoculars to video display terminals with zoom-in capability, may be utilized to enhance visual detection. In any event, detection mechanisms employed in visual surveillance systems employ colour and/or brightness contrast to "identify" targets.

(b) Making targets hard to find in the visible light spectrum (wavelength from 400-700 millimicrons) is primarily concerned with the development of ever more effective camouflage patterns and with techniques for characterizing the effectiveness of the camouflage for particular terrain. The techniques in use today largely involve painting, colouring, and/or contour shaping to allow an object to better blend with the surrounding environment.

(c) Other than colour adaption to the background, these techniques have involved obscuring the contours of an object by covering the object with camouflage material such as nets or leaf cut tarpaulins. Such covering camouflage is good for visual concealment because the outlines of covered objects are disguised and difficult to discern from the surrounding natural environment, provided that the colour scheme is harmonized with the surrounding natural environment. Thus, there are special nets for woodlands, for deserts, and for snow, all of which have very different colour schemes.

Figure 13

[11] US Patent and Trademark Office (Thermal and Visual Camouflage Systems)

(d) In the visible spectrum, successful camouflage may be limited by:-

(i) Camouflage patterns painted on a conventional surface are unable to change and a fixed camouflage pattern is inappropriate for the variety of backgrounds encountered.

(ii) One observer sees a military target against a rocky background while another observer sees the target against a forested background, while a third observer sees the target against a red barn. The current state of the art does not allow the military target to be effectively camouflaged for all these observers simultaneously or in real time.

(iii) When either the object or the observer moves, the background against which the target was camouflaged changes and thereby reduces the effectiveness of the camouflage pattern employed.

(iv) Most camouflage paints, irrespective of their colour in the visible spectral range, tend to have high emissivity in the IR spectral regions, wherein such emissivity is significantly higher than those of most naturally occurring backgrounds. Therefore, these targets can be clearly detected by imaging devices operating in the IR spectral ranges.

(v) Even the combination of several techniques may not effectively camouflage an object from detection. For example, known camouflage covering material, such as nets, generally have a very open, apertured structure. The proportionate covering of such conventional materials is only about 50-65%. This has been found to be insufficient when surfaces with high emmissivities are still detectable through the covering's apertures. Likewise, such coverings would also be ineffective in masking warm objects against detection by thermal reconnaissance.

<u>Visual Camouflage for the Navy</u>

'If if moves Salute it, otherwise Paint it Grey' – Naval Quip.

16. During World War I, the British and Americans faced a serious threat from German U-boats, which were sinking allied shipping at a dangerous rate. All attempts to camouflage ships at sea had failed, as the appearance of the sea and sky are always changing. Any colour scheme that was concealing in one situation was conspicuous in others. U-boats did not aim their torpedoes directly at a ship to sink it. Because the target was moving, it was necessary to aim ahead of its path in order for the torpedo to arrive in the correct spot at the same time as the ship. If the torpedo is too early or too late, it will miss. The primary goal of dazzle painting was to confuse the U-boat commander who was trying to observe the course and speed of his target. It continued to be used till the end of World War II. However, continuous development in radar and sonar eventually eliminated the requirement of visual acquisition for torpedoes. This meant the demise of the Dazzle Paint.

17. <u>Ships.</u>[12] The modern ships paint requirements stem more from more relevant requirements like corrosion resistance, reduced IR signature, application and costs etc. Some interesting facts about choice of colour are as follows:-

(a) <u>Haze Grey</u>.

(i) Low visibility to surface observers in hazy or foggy weather especially when it is accompanied with periods of weak sunlight.

(ii) High visibility in bright weather when seen against the water.

(iii) Useful in submarine infested areas, where periscope observers will see a vessel entirely against a sky background.

(iv) High visibility under searchlight, and down-moon at close ranges. Very low visibility on moonless nights and at twilight.

[12] Ship Camouflage Instructions United States Navy

(b) Ocean Gray System.

(i) Low visibility to surface observers in bright sunny weather and down-moon on moonlit nights.

(ii) High visibility in bright weather to aerial observers at close ranges, but not necessarily so at distant ranges. Its maximum utility would be against surface observation in areas where sunny weather is common.

(iii) Moderately high visibility in overcast weather or on moonless nights.

(c) Thayer System.

(i) Lowest visibility to surface observers on moonless nights and in overcast weather.

(ii) High visibility down-sun or down-moon in bright clear weather, but reduced visibility up-sun and up-moon in all weathers.

(iii) Especially well adapted for winter use in Northern areas where nights are long and days frequently overcast. It would prove useful against submarines in any area where attacks occur mostly at night, but in bright weather it would be very visible to surface raiders, or to high-flying aircraft, when observed down-sun.

(d) Navy Blue System.

(i) Lowest visibility to aerial observers day and night in all types of weather.

(ii) Low visibility under searchlight. High visibility to all surface observers in all types of weather.

(iii) Considerable course deception to surface observers in all types of weather.

(e) Graded System. This measure is intended for use on combatant ships in areas where bright weather with fair visibility predominates, and high angle aerial observation is unlikely, and there is a likelihood of a gunnery engagement. There will be some reduction of visibility when viewed from low-flying planes, and from higher altitudes at extended ranges.

18. Submarines.

(a) Black System.

(i) Lowest visibility when submerged.

(ii) When on surface low visibility to aerial observers in all types of weather, except up-sun in bright weather.

(iii) When on surface high visibility to surface observers in all types of weather.

(b) Gray System.

(i) Low visibility for submarines when on the surface both to surface observation and low angle aerial observation.

(ii) High visibility to high angle aerial observation when the submarine is on the surface or submerged in clear water.

(iii) Will not offer the same protection as the black system to submerged submarines operating in areas where aerial observation is an important factor, but will be lower visibility against either sea or sky when observed by surface ships.

Corrosion Inhibitors.[13]

19. Every corrosion inhibitor, including volatile ones, should:-

(a) Be capable of establishing a stable bond with the metal surface in a given environment of a certain range of acidity and pressure.

(b) Create an impenetrable layer for corroding ions.

20. Vapour Phase Corrosion Inhibitors (VCIs). VCIs are chemical compounds having significant vapour pressures that allow vaporization of the molecules and subsequent adsorption of these on metallic surfaces. The advantage of these vapour phase corrosion inhibitors is that the vaporized molecules can reach hard-to-reach areas commonly found in electronic enclosures, between two metal flanges and similar other systems. This is being successfully used by many modern navies.

[13] K. L. Vasanth - Corrosion Inhibition In Naval Vessels

Signatures in the Infrared and Thermal Regions

21. Infrared and Thermal Detection.

(a) Passive systems which operate in the infrared (IR) wavelength bands, the 0.8 to 14 micrometer portion of the electromagnetic spectrum, which include the solar band, the high temperature band and the low temperature band, operate by homing-in on the contrast between the IR signature and the IR signature of the surrounding environment.

Figure 14

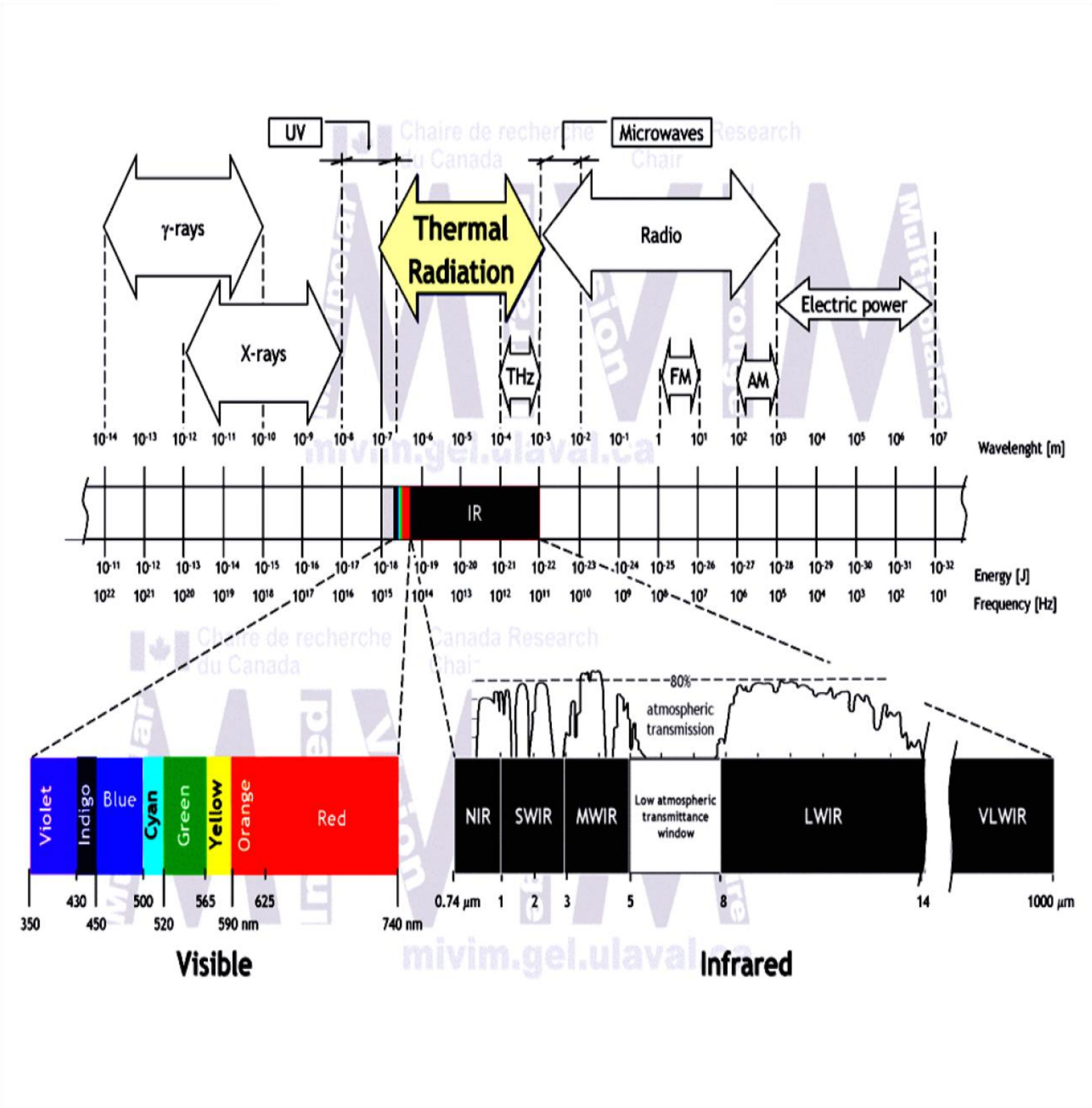
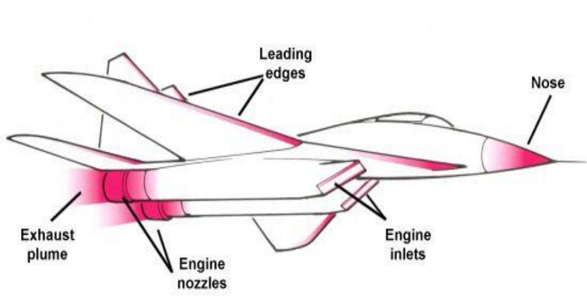


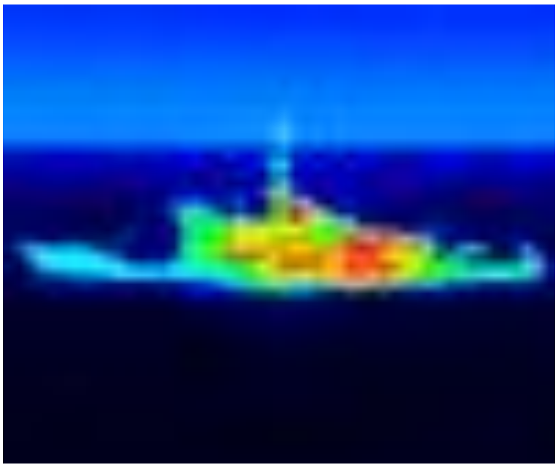
Figure 18



Aircraft

- Considered as Grey Body with Emissivity 0.9
- Exhaust in general region of 3µm.
- Main Sources- Tail pipe and Plume

Figure 17



Ships

- Two Signatures:-
  - 8 – 14 µm spectral band. Prime movers of ship, gas turbines.
  - 3 – 5 µm spectral band. Hull of ship and superstructure.
- Detected against two backgrounds:-
  - Sea.
  - Sky.

Figure 16

Fighting Vehicles

- Two Signatures:-
  - 8 – 14 µm spectral band. Engine, Exhaust, Gun, Running Gear etc.
  - 3 – 5 µm spectral band. Hull etc.

Figure 15

Personnel

- Two Signatures:-
  - 32% of irradiated energy emitted 8 – 13 µm spectral band.
  - 1 % in the 3.3 – 4.8 µm spectral band.
- Emissivity – 0>99 at ʎ longer than 4 µm.

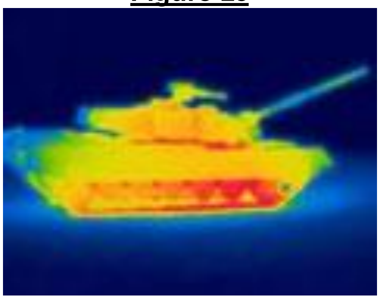
(b) Finding targets in the IR spectrum utilises target size and apparent temperature differences (Δ T) between the target and the background, a summary measure that combines target background physical temperature difference and target background emissivity difference. Some targets contain highly concentrated heat sources which produce very high localized temperatures. There are also targets that contain a large number of heat sources with distinctive shapes which form easily recognizable patterns. As the contrast sensitivity of solid state detectors improves, it becomes possible to discern, for example, the number of cylinders in a gasoline engine and other subtle distinctions such as a change in fabrication material etc.

(c) More specifically, many targets have internal heat sources which create a temperature contrast with the natural background which further enhanced the detectability of such targets by means of IR sensing devices.

For example,

A tank generates large amounts of heat in the engine compartment and exhaust pipe, as well as from electric generators and motors. When the guns are fired, their barrels become heat sinks. Friction while the tank is moving heats the rims of the drive and the idler wheels and their central bearing portions. The track also becomes heated by friction with the wheels. The bearing area between the turret and tank body can also become heated. Moreover, radiant energy from the sun may be absorbed by the steel shell of a tank during the daytime, and at night time such energy reradiates from the shell, providing a clear IR signature against a cool background such as trees or hills. In addition, as mentioned above, the emissivity of paints tends, on average, to be significantly higher than those of most naturally occurring backgrounds. Therefore, a tank painted with camouflage paints can be clearly detected by imaging devices operating in the infrared spectral ranges.

Figure 19



Hot Tank

Figure 20

Cold Tank

(d) To mask ΔT differences, some IR camouflage involves the use of subsystems to alter the surface of the object, such as forcing heated or cooled air over an object to match the object's temperature to that of the surrounding environment. Of course, these subsystems themselves often have extraordinary power requirements which generate their own IR signature. Another technique has been to deploy decoy IR sources in an environment to radiate IR signatures equal to that of any specific target. The most common involves complete covering or shielding of an object with a material cover, such as a tarpaulin, in order to hide an objects IR signature.

(e) Typically, shielding provided by only a camouflage material cover will result in heating of the object covered by the material, such that while the structure and contours of such an object cannot be observed visually, the higher temperature of any exposed surface will be vulnerable to detection by IR detection devices. To overcome this effect, double-layered cover structures are utilised, wherein the outer, exposed camouflage material is insulated from a covered source of heat by a layer of insulating material arranged under and spaced apart from the outer material. The exposed outer camouflage material may still be heated or cooled by external conditions, yielding an IR signature that differs from the surrounding environment and has limited success as:-

(i) Camouflage material has different heat transfer characteristics than the background resulting in changing apparent temperature differences between target and background over a given time interval.

(ii) Camouflage net material is vented to prevent heat build up, but winds cause the material to move which results in a blinking IR signature that is a clear beacon for detection.

(iii) One observer seeing an object against a hot background (e.g. ground) and a second observer seeing the same object against a cold background (e.g. sky), allows for a situation where the current state of the art does not permit the object to simultaneously be made to appear hotter to the first observer and colder to the second observer, and when either the object and/or the observer moves, the apparent temperature

22. The requirement seems to be for a camouflage system to prevent both visual and IR detection which provides real-time control of:-

(a) The effective emissivity (band average and spectral) in the thermal wavelength region.

(b) Apparent colour in the visible wavelength region.

23. Effective ways to reduce the thermal and IR signatures may be:-

(a) Screening to Diminish Heat Radiation. [14]

Figure 21

A thermal blanket can be used to screen an objects heat radiation. The blanket has low emissive surface, which in combination with the screening, considerably reduces the object's heat signature. Example - This Leopard tank is equipped with a thermal blanket on the turret. The thermal blanket is designed to reflect heat away from the tank and keep the crew compartment cooler.

(b) Creating a Thermal Signature Compatible with the Environment. To use only a thermal blanket would result in a surface showing a uniform temperature. But in combination with a thermal camouflage net that consists of different polymers in a pattern, which is combined with an immediate later of metal, a blend of warm and cold surfaces is created. The resultant is a thermal signature that naturally blends with the environment. At the same time, the net also provides adequate protection in the NIR spectrum.

(c) Use of Liquid Nitrogen. Recent reports indicate the use of liquid nitrogen in moments of high threat to shield the hot areas. NASA's X15 program is known to have experimented with it where when The X-15 launches away from the B-52 mother ship with its rocket engine ignited, the white patches near the middle of the ship are frost from the liquid oxygen used in the propulsion system, although very cold liquid nitrogen was also used to cool the payload bay, cockpit, windshields, and nose.

Figure 22

(d) Change in Geometry. The change in shape, surface area of the potentially greater sources will facilitate quicker dissipation.

(e) Insulation by Other Structures. If nearby structures were built out of titanium or other heat resistant alloys they may provide incidental camouflage.

(f) Use of less conductive materials (ceramics and composite materials), Anti IR paints etc. On ships - use of effective water wash systems etc also facilitate reduction of signature.

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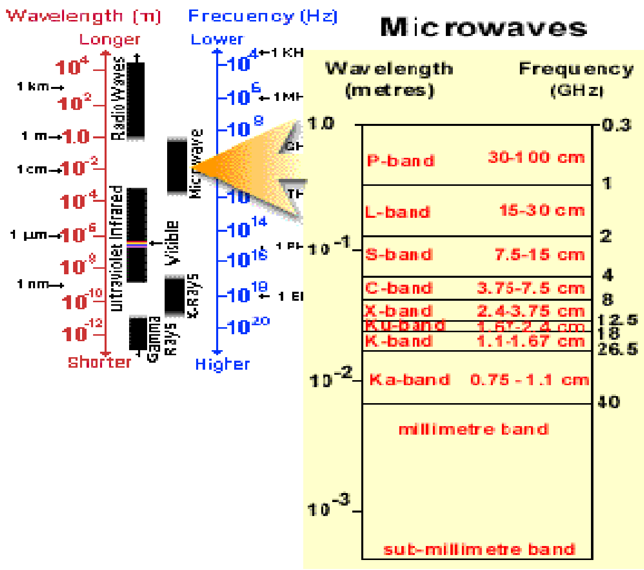
[14] www. flickr.com

Microwave Management

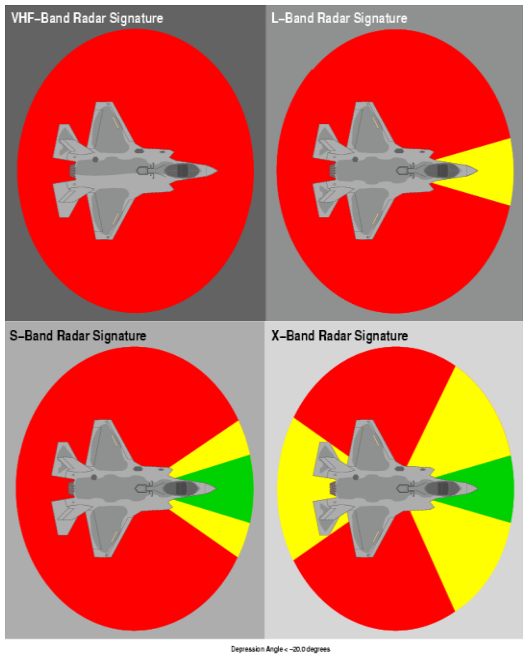
24. Introduction. Microwave camouflage deals with the various means that are employed to defy detection in the microwave region of the electromagnetic spectrum (300 MHz to 300 GHz). As the radar is the chief sensor of the microwave region, microwave camouflage is actually referred to as radar camouflage or radar countermeasure. Broadly speaking microwave sensors may be classified as active or passive.

Figure 23



25. Radar. Acronym- Radio Detection and Ranging.

Figure 24



(a) Principle. The principle behind their operation is the fact that electromagnetic waves get reflected whenever there is a change in the properties of the medium. The properties involved are:-

(i) Conductivity.

(ii) Permittivity.

(iii) Permeability.

(b) Types of Radars.

(i) Continuous Wave (CW) Radar.

(ii) Frequency Modulated CW Radar. .

(iii) Pulse Doppler Radar and Moving Target Indicator (MTI).

(iv) Tracking Radar.

(v) Side Looking Air Borne Radar (SLAR).

(vi) Synthetic Aperture Radar (SAR).

(vii) Millimetric Wave Radar.

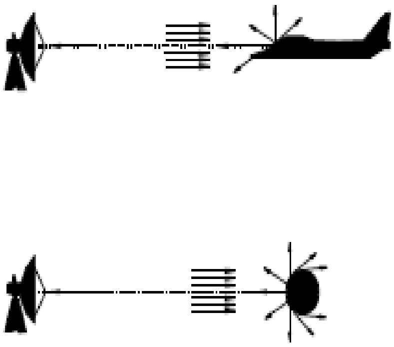
(viii) Phase Array Radar etc.

(c) Criticality. Radar Cross Section of the target. It is a measure of how detectable an object is with a radar.

26. Radar Cross Section (RCS)[15]

(a) Radar cross section is the measure of a target's ability to reflect radar signals in the direction of the radar receiver, i.e. it is a measure of the ratio of backscatter power per steradian (unit solid angle) in the direction of the radar (from the target) to the power density that is intercepted by the target.

Figure 25



(b) The RCS of a target can be viewed as a comparison of the strength of the reflected signal from a target to the reflected signal from a perfectly smooth sphere of cross sectional area of 1 m^2 as shown in the figure.

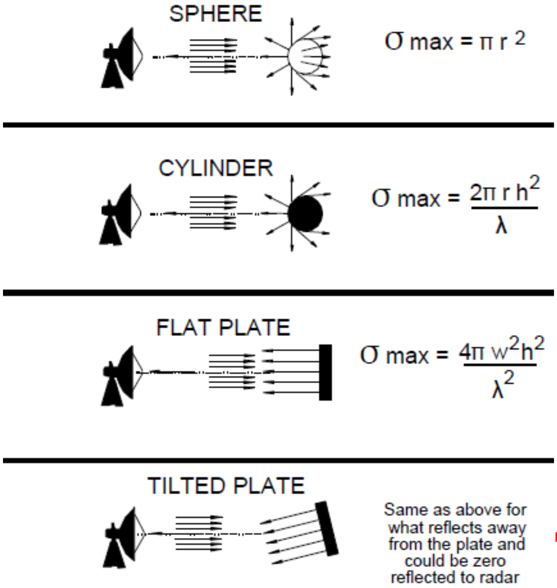
(c) The conceptual definition of RCS includes the fact that not all of the radiated energy falls on the target.

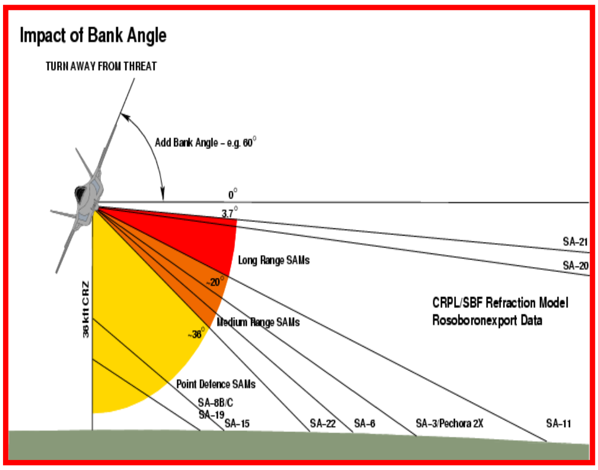
F = Projected Cross Section x **Reflectivity** x **Directivity.**

(i) Reflectivity. The percent of intercepted power reradiated (scattered) by the target.

(ii) Directivity. The ratio of the power scattered back in the radar's direction to the power that would have been backscattered had the scattering been uniform in all directions (i.e. isotropically).

Figure 26





[15] www.microwaves101.com

(d) This is a complex statement that can be understood by examining the monostatic (radar transmitter and receiver co-located) radar equation one term at a time:

$$P_r = \frac{P_t G_t}{4\pi r^2}\sigma\frac{1}{4\pi r^2}A_{eff}$$

Where:-

P_t = Power transmitted by the radar (Watts)

G_t = Gain of the radar transmit antenna (dimensionless)

r = Distance from the radar to the target (meters)

σ = Radar cross section of the target (meters squared)

A_{eff} = Effective area of the radar receiving antenna (meters squared)

P_r = Power received back from the target by the radar (Watts)

This implies $P_j \propto \sigma$ and $r^4 \propto \sigma$

27. RCS Reduction[16] Reduction of RCS of military objects is the same as suppression of radar signature of the object concerned. In classical terms it may be known as microwave camouflage and constitutes a major component of stealth or Low Observable Technology (to be discussed later). Basic techniques for reduction of RCS constitute the following categories:-

(a) Shaping. (To be discussed subsequently).

(b) Use of Radar Absorbing Material (RAM). (Elucidated subsequently in Materials for Camouflage Application).

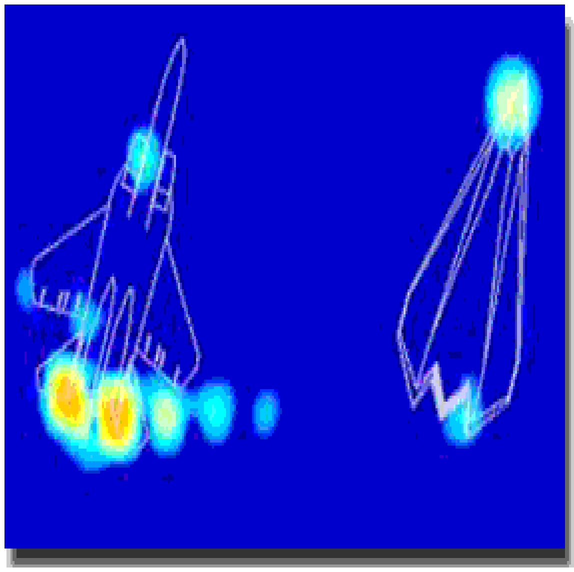
(c) Passive cancellation. Involves cancelling an echo source in the object with the help of another echo source whose amplitude and phase have to be adjusted and is very difficult to achieve (not commonly used).

(d) Active cancellation. Involves emission of a signal by the target whose amplitude and phase cancel the reflected energy. The target must be able to follow carefully the arrival of the incident signal with respect to its angle of incidence, intensity, frequency and wave form (not commonly used).

[16] JV Ramana Rao – Introduction to Camouflage and Deception

28. Shaping.[17] It is best carried out at design stage to ensure no large, wide-angled sources of RCS, such as orthogonal corners. Subsequently, reduced micro-geometry techniques can be applied, offering a reduction in RCS by removing or re-designing exposed subsystems, to concentrate radar signature in a few low-threat sacrificial directions, leaving the RCS low elsewhere. Careful design can substantially reduce the RCS by using shaping, smoothing surfaces, minimizing the number of openings, and retracting weapons and sensors into the structure when not in use.

Figure 27



(a) Avoid design features creating strong reflections in the direction of radar.

(b) Use of non-metallic materials.

(c) Absorb rather than reflect the radar energy.

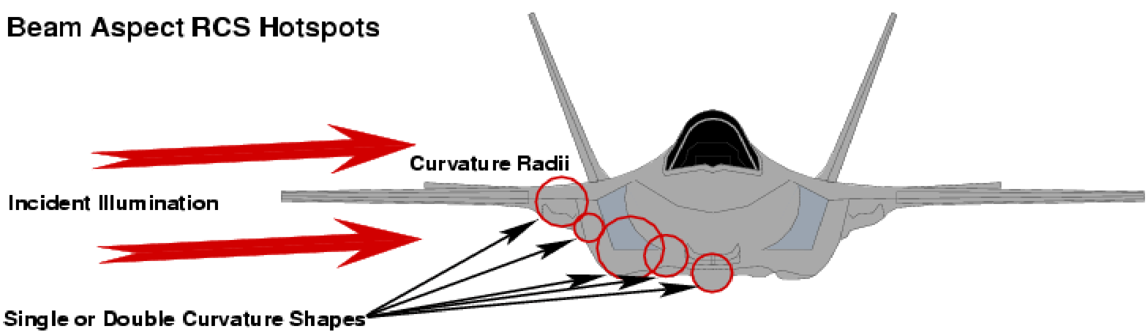
(d) Mask or cancel out any remaining reflections.

29. No single approach will provide sufficient RCS reduction. Some important design guidelines observed are as follows:-

(a) Avoid the use of large flat surfaces.

(b) Curve the exhaust surface and other such parts to a concave shape, as the convex shape would be reflective.

Figure 28

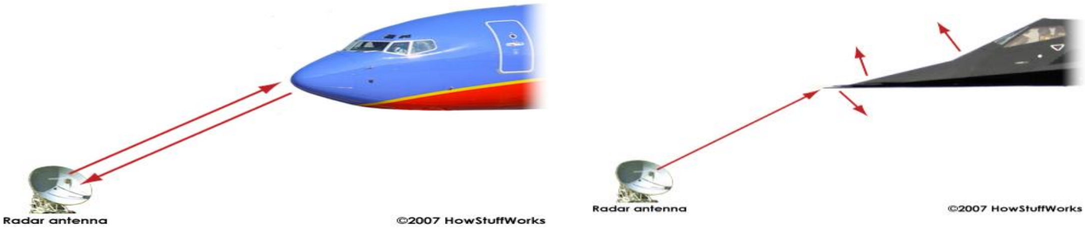


[17] PJ Gates- Ship Detection and Counter Detection.
www.ausairpower.net
www.airplanedesign.info

(c) Avoid discontinuities in shape, such as corners and abrupt change in profile, blending and smoothing all appendages and surface junctions.

(d) Flat Panel Design consisting of several surfaces, each reflecting in a different direction is less likely to betray the position.

Figure 29



(e) Aerodynamic shape of the target will decrease the amount by which the reflected energy is shifted away from the incident energy. By curving the leading edge, the design can ensure that the reflected energy is not all returned in the same direction, but is weakened by being spread over a range of harmless directions.

(f) Cavities or re-entrant structures have a high RCS. Inlets and the exhausts should be moved to the lower surfaces (in case of ships) and upper surfaces (for aircraft) where they can be screened away by the body.

(g) The radome or antenna sticking out is a good source of reflection. There is a need, therefore, to use Radio Sets in the millimetric wave range with reduced antenna size, as also the use of flat planar arrays which have a low RCS, or use retractable antennas.

Figure 30

(h) <u>Sweep Angle.</u> The wing leading edge can be a strong reflector in the forward area. This reflected energy from an incoming head on radar signal will be reflected at an angle equal to twice that of the leading sweep angle. At the point of impact, thus increase in the sweep angle will increase the amount by which reflected energy is shifted away from the forward sector, thus reducing the chances of radar detection from the forward quarter. In other words, at high angles of sweep, most of the reflected energy is deflected at angles away from the critical forward sector. On most aircraft, the leading and trailing edges are straight or near straight so the reflected energy will be concentrated over a narrow range of angles. By curving the leading edge or using compound sweep, the design can arrange that the reflected energy is not returned in the same direction but is weakened by being spread over a range of harmless directions.

Acoustic Signatures[18]

30. The introduction of towed-array sensors has alerted surface navies to the importance of noise control, both to reduce the likelihood of detection by enemy sonar and to enhance the performance of their own sensors. Hull mounted and variable depth sensors also benefit from such efforts. Silencing techniques include mounting equipment such as engines on rafts to isolate their vibration from the hull, surrounding propulsion equipment with acoustic enclosures, employing Prairie/Masker belts that produce streams of air bubbles to hide propeller noise, and by applying sound-deadening materials to the hull.

31. Four main types of acoustic coatings are available, which may be employed individually or in combination. These are:-

(a) Anechoic Coatings. They absorb acoustic energy by exploiting visco-elastic loss and local strain deformations. They may be applied to the external surfaces of a ship's hull in order to reduce its active signature, and near sonar arrays to prevent unwanted reflections from incoming acoustic energy.

(b) Transmission – Loss Coatings. They act as acoustic reflectors that direct energy into areas where its effect is not significant.

(c) Decoupling Coatings. They may be applied to the hull exterior to prevent internally generated noise from entering the surrounding water.

(d) Damping Coatings. They reduce the effects of flexural vibrations within the hull, thereby preventing re-radiation into the water at acoustic discontinuities such as ribs, frames and where a sonar dome joins the hull.

32. Maintenance of an acoustic hygiene is a command responsibility that requires an overall systems approach rather than one of merely treating individual symptoms. Ship design can contribute perhaps 60% of the achievable reduction in acoustic signatures, with the remainder resulting from operational techniques and implementation of good practices over the life of the vessel.

33. In land systems, acoustic signatures have little significance in conventional environments especially for tanks etc. They employment in counter insurgency and urban warfare operations however exposes this weakness. The primary causes are:-

(a) Machinery, Gear Train, Motors etc. Mostly between 10 and 1000 Hz. Effective noise insulation measures can be taken to reduce its effect.

(b) Friction of Tracks, Flow Noise etc. Generally in the 1 to 10 Hz band.

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[18] Rear Admiral John Hervey - Signature Reduction- Submarines, Brassey's Sea Power

<u>Magnetic and Electro-Magnetic Signatures</u>[19]

34. <u>Magnetic Signatures</u>. Magnetic signatures of the warship are due to ferromagnetic material of the ship itself and integral equipment installed in the ship.

35. The reduction in magnetic signature could be achieved either by magnetically treating the ship in special magnetic treatment facilities (deperming) or fitting the ships by special active degaussing system. In the degaussing system, coils are installed in the ship while designing the hull. Electric current is passed through these coils, strength of which can be controlled from a computerised control panel. Latitude and longitude of the ship at commencement of sailing are fed in the system. The system ensures that any time and in any geographic position, the ship's magnetic signature is minimised. For vessels being accepted into service for the first time and for the ships returning to duty after refit or alteration, degaussing system is calibrated/ checked for its performance at special degaussing ranges. However, the disadvantage of deperming is that, it is not permanent and the vessel will need to be checked periodically in order to maintain the desired effect.

36. <u>Magnetic Anomalies</u>. The Earth is surrounded by a weak magnetic field, which varies in different Geographic areas. The ship is at a risk to produce measurable distortions or anomalies in this background, when its own magnetic field or signature exceeds a certain limit. These can be detected, from below by a magnetic mine or above, by an aircraft fitted with Magnetic Anomaly Detection (MAD) equipment. The main reason for this signature is the acquisition of magnetism, permanent and induced, by the ship during the ship building process or due to the compression and expansion of the hull when the ship is at sea.

37. <u>Deperming</u>. Permanent Magnetism can be reduced by a process called 'deperming'. It involves placing the ship inside coils, through which high energy DC electrical circuits are passed for short time intervals, first with one polarity and then the opposite. The currents create large magnetic fields, which shock ferrous metal molecules out of their existing alignments. After an initial shake up phase, the current pulses are gradually strengthened, until the metal is driven to magnetic saturation, then decreased again exponentially towards zero, to bring the signature below required level. The magnetic state of the ship is checked after each shock, by taking readings from magnetometers, fitted in lines beneath the deperming berth.

38. <u>Electro Magnetic Signatures</u>. One of the most effective weapons against ships in littoral waters is the naval mine. The majority of influence mines utilize the magnetic signature of the vessel as a trigger. Mines could be designed to exploit the DC and AC field signatures. Control of all exploitable electromagnetic (EM) signatures is thus vital to preserving ship's survivability.

[19] Rear Admiral John Hervey - Signature Reduction- Submarines, Brassey's Sea Power

39. The electromagnetic signatures can be further sub divided into following categories:-

(a) Static Electric (SE) Signature. The SE signature is the electric field due to the corrosion protection current, which flows through the seawater.

(b) Corrosion Related Magnetic (CRM) Signature. It becomes more important as ferromagnetic signatures are reduced. It is the coupled magnetic field associated with the SE signature.

(c) ELFE Signature. These extremely low frequency (ELFE) signatures can be further separated into distinct frequency bands which are as follows:–

(i) Power Frequency (PF) ELFE (at low hundreds of Hz).

(ii) Shaft Rate (SR) ELFE (up to tens of Hz).

40. The main source of the (PF) ELFE signature is the modulation of corrosion protection currents due to poorly filtered impressed current corrosion protection (ICCP) system power supplies. Other sources, such as on-board AC electric circuits and rotating machinery can also produce such signatures, but these electro-magnetic fields are generated within the vessel and attenuate rapidly through the hull of the vessel. The (SR) ELFE signature arises from the modulation of the corrosion protection current flowing to the propeller, which results mainly from the fluctuating electrical resistance of the shaft bearings as the shaft rotates.

41. Threats Posed by EM Signatures. The EM signatures discussed here can pose both near field and far field threats, as explained below:-

(a) The SE signature is a potential mechanism for activating mines and so presents a near field threat.

(b) The CRM signature decays at a lower rate than the ferromagnetic signature and, therefore, may be assumed to propagate further than ferromagnetic signature. Thus the CRM signature may present a detection threat in the far field.

(c) The threats posed by the ELFE signatures have been considered as both a near field mine threat and far field detection threat.

42 Reduction in SE and CRM Signatures. An ICCP system of a vessel can be set to have low SE and CRM signatures without any design or hardware changes. It is achieved by adjustment of the vessels ICCP system in conjunction with measurement of the signature on a range or through modelling. Careful location of ICCP system anodes and reference electrodes close to significant current sinks (near to propeller) and suitably spread over distributed current sinks (the hull and appendages) is recommended.

Signature Management for Helicopters[20]

43. Signatures.

(a) Visual.

(i) Sun glints from cockpit, windows and metallic rotor blades

(ii) Engine exhaust glow and cockpit lighting.

(iii) Movement in static background attracts the attention of human vision.

(b) Infrared. Sun reflections and engine emission are mainly in the 3-5 µm transmission band, and blackbody radiation from the fuselage in the 8-12 µm band. Engine plume emission is strong around CO2 emission line at 4.3 µm; the spectrum is broader if the plume is contaminated or contains solid particles.

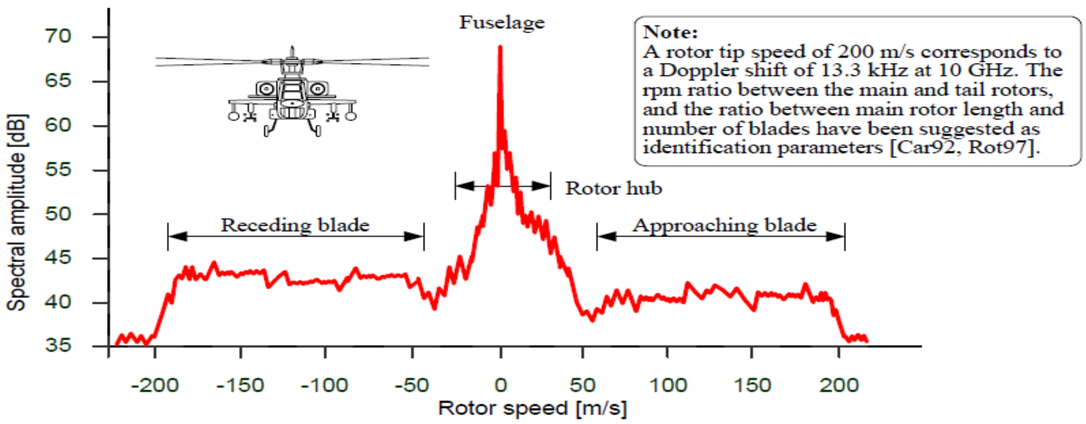
(c) Acoustic. Aural Strong noise is generated by the anti-torque system, engine, and main rotor.

(i) Rotor noise frequency is the rpm times number of rotor blades, usually 20-40 Hz for the primary frequency of a four-blade main rotor.

(ii) The ratio of the main and tail rotor frequencies is type-specific and allows identification of a helicopter.

(iii) The particular feature of noise is propagation behind line of sight obstacles. Uneven rotor blade spacing offers best potential for noise reduction.

Graph 2



[20] Johnny Heikell - Electronic Warfare Self-Protection of Battlefield Helicopters: A Holistic View

(d) Radar Backscatter. Fuselage RCS average some square meters. Both static and rotating flash points. Rotor flash duration in the order of 0.25-0.5 ms.

(e) Emission. Radars, communication radios, IFF systems, obstacle warning systems and other on-board transmitters emit signals that can be detected and identified.

44. Signature Reduction.

(a) Visual. Reduction of airframe size, particularly the frontal view; use of camouflage painting, fuselage markings in low-contrast colours, reduction of sun glints or their number of directions. Rotor frequencies above 16 Hz, low-level flight in the shadow of clouds to avoid revealing shadows on the ground. Nape of Earth (NOE) flight over dusty ground to be avoided.

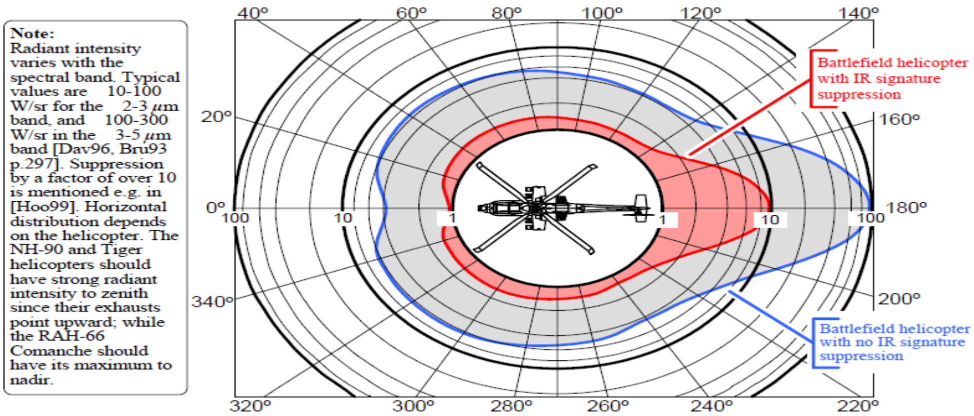
(b) IR. IR suppressors decrease heat signatures at the cost of additional weight on the platform. Suppressors are claimed to reduce the temperature of AH-64 Apache engine parts from 590 ºC to 150 ºC. Fuselage emission and solar reflex suppression by IR paint. Frontal aspect of the helicopter is cooled by the rotor downwash. Signature reduction is simplified by 5ºC or more temperature differences in the surrounding.

(c) Acoustic. Aural Reduction of main rotor tip speed lowers noise, but at the cost of lift. Other noise reduction methods are rotor blade tip shaping, increased number of blades, active blade control, uneven tail rotor blade spacing, “fan-in-fin”, No Tail Rotor (NOTAR) and spectrum shaping to where the human ear is less sensitive.

(d) Radar Backscatter. Reduction through all-composite rotor blades, “fan-in-fin”, rotor hub fairing, radar absorbing structures and paint, conductive windshield coating, fuselage geometrics, internal weapon load, impedance control, etc.

(e) Emission. Low Probability of Intercept (LPI) gains through emission control; spread spectrum; power, temporal, and spatial emission control; utilization of mm-waves and atmospheric absorption peaks; etc.

Figure 31



MATERIALS FOR CAMOUFLAGE APPLICATION

Radar Absorbent Paint (RAP)

45. RAP is ideal for application to complex shapes, has a long life and can be used on surfaces such as decks that are subjected to high wear. Alabama based Signature Products has developed a RAP based on Carbon 60 (C-60), that uses polymers of high molecular weight to provide a matrix in which are embedded cyanate "whiskers" of C-60 that is modified to accommodate a metal. The conducting material converts incident microwave energy into heat, which is then dissipated.[i] The Swedish company Divinycell International has developed a Radar Absorbent Foam that when combined with the effects of shaping and RAP, reduces the vessel's radar signature virtually to zero.

Radar Absorbing Material (RAM)[21]

46. RAMs in the form of surface coatings or structural materials play an important role by complementing or augmenting reduction in RCS. Radar echo includes specular (direct) reflections, edge diffractions, multiple reflections and creeping waves (which propagate along the body surface and emerge at the opposite edge).

47. The tangle of variables makes the design of RAMs tricky. This is further complicated by:-

(a) The fact that different radars affect the target in different ways.
(b) The continuous improvements in radar system performance.

48. In most RAMs, the first step is to make total pathway (of energy within the RAM) equal to half a wavelength so that the residual reflection from the back face is exactly out of phase with the front face reflection. However, RAM can be much thinner than the nominal wavelength of the radar and still achieve cancellation because the wavelength inside the material is much shorter than in free space.

49. RAMs are tailored so that the energy that travels through them bounces off the substructure and escapes. Additionally, the RAM coatings applied on the surfaces of the aircraft for stealthy applications must be thin, weigh as little as possible, withstanding stressing temperatures, pressures and erosive environments, generally be covered by materials to keep things together structurally and must not disturb the smooth contours of the air frame (when applied to air craft).

[21] JV Ramana Rao – Introduction to Camouflage and Deception

50. More modern materials provide wideband coverage, usually from 6 GHz to 18 GHz, with attenuations of 20-25 dB. There are two broad classes of RAMs[22] :-

(a) Resonant Absorbers. These are designed for use at a specific frequency, but maintain some effectiveness over a range of frequencies on either side of their normal operational point. The goal of the RAM designer is to create such a material whose front surface will admit a radar signal, rather than reflect it. Once within the RAM, the radar waves should then be absorbed, dissipating its energy in the form of heat. When the radar waves strike such a RAM, its limited conductivity causes losses. In a resonant RAM, a resistive screen is positioned in front of the black plate. The resistance of the screen is such that, 50 per cent of the incoming radar wave is reflected from the screen surface, while the remainder passes through to be reflected from the back surface. The two surfaces are so positioned that the reflected waves from each of these surfaces interfere destructively.

(b) Broadband Absorbers. Wide band RAMs are created by adding a carbon-loaded plastic material to the base. The thicker the material, the better the absorption (up to 99.9% is possible). The main problem with all the RAMs is that they are, by nature, very heavy and hence impair the efficiency. A broadband magnetic absorber known as ‘Advanced Absorber Products: AAP-21’ has been created. It is a ferrite based spray able coating, which dries in 40 minutes and hardens in 12 to 24 hours. Its RAM properties depend on the thickness to which it is applied. Magnetic RAMs are the most effective at lower frequencies while dielectric types are effective at the higher frequencies. The logical approach, therefore, is to combine the two and create Hybrid RAMs effective over highest possible range of frequencies.

51. Types of RAMs.

(a) Magnetic Materials.[23] Magnetic materials are those whose relative permeabilities are different than that of free space. The presence of permeability factor greater than one gives greater freedom in tailoring the intrinsic impedance and index of refraction to meet the needs of absorber performance. RAM performance is a function of particle size and in ideal conditions individual particles contains sufficient number of magnetic domains, that they are isotropic. Magnetic absorbers (especially sintered ferrites) have usefulness at higher temperatures too. Currently research is on to combine magnetic RAM with Dielectric to increase the broadband coverage as magnetic RAM covers primarily the UHS and VHF bands.

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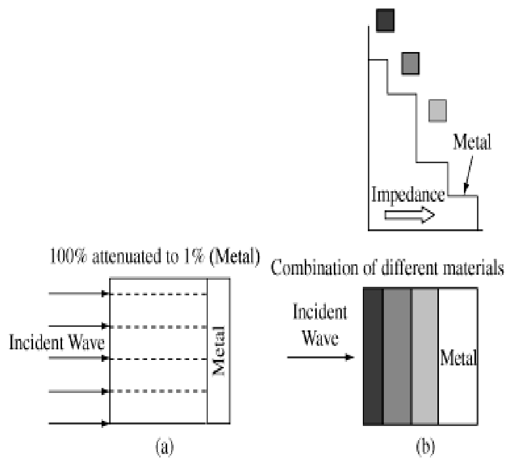
[22] Dr DG Kiely- ECCM and Countermeasures. Naval Electronic Warfare
[23] Eugene F. Knott, John F. Shaeffer, Michael T. Tuley- Radar Cross Section

(b) Dielectric Materials. [24]

Figure 32



Dielectrics or graded absorbers operate by effectively altering the dielectric properties of a material at different depths. The material surface impedance is designed to closely match that of free space (370 Ω) which encourages radar wave absorption and produces little reflection from the front face as the wave progresses through the material and loses and dissipates the wave's electromagnetic energy. These losses can be explained in terms of phonon-photon conversion phenomenon in polar dielectric insulators (the polarisation induced in crystal lattices by incoming electromagnetic fields relaxes into normal oscillation modes which eventually redistribute the electromagnetic energy into thermal photons). In the category of microwave absorbers, materials are available in the following forms:-

(i) Honeycomb. Lightweight broadband absorber (2-18GHz).

(ii) Open Structured Netting Material (with Urethane Foam). Rugged, lightweight and low cost (8 – 100 GHz).

(iii) Salisbury Screen. (Discussed separately).

(c) Artificial Dielectrics. [25] A composite of conducting particles dispersed into a dielectric insulating material (ceramic or polymer matrix) is known as artificial dielectric. These composites make use of metallic behaviour of conductive particles to get effective and controlled microwave absorption.

(d) Conducting Polymers.[26] The most important criterion for selection of monomers to give conducting polymers is the formation of conjugate bonding in the backbone of the polymer obtained. Such polymers on interaction with electron acceptors (oxidising agents) or electron donors (reducing agents) create carriers which get doped with these species. In the application of conducting polymers as anti radar material their response to the frequency range of 10^7 -10^{11} Hz is of special interest. The ability of conducting polymers to absorb microwave and other electromagnetic radiation results in another interesting application viz. welding of plastic joints through remote heating.

[24] JV Ramana Rao – Introduction to Camouflage and Deception
[25] Abid.
[26] Abid.

(e) Iron Ball Paint.[27] One of the most commonly known types of RAM is iron ball paint. It contains tiny spheres coated with carbonyl iron or ferrite. Radar waves induce molecular oscillations from the alternating magnetic field in this paint, which leads to conversion of the radar energy into heat. The heat is then transferred to the aircraft and dissipated. The iron particles in the paint are obtained by decomposition of iron pentacarbonyl and may contain traces of carbon, oxygen and nitrogen. A related type of RAM consists of neoprene polymer sheets with ferrite grains or carbon black particles (containing about 30% of crystalline graphite) embedded in the polymer matrix. The tiles were used on early versions of the F-117A Nighthawk, although more recent models use painted RAM. The painting of the F-117 is done by industrial robots with the plane covered in tiles glued to the fuselage and the remaining gaps filled with iron ball paint. The United States Air Force introduced a radar absorbent paint made from both ferrofluidic and non-magnetic substances. By reducing the reflection of electromagnetic waves, this material helps to reduce the visibility of RAM painted aircraft on radar.

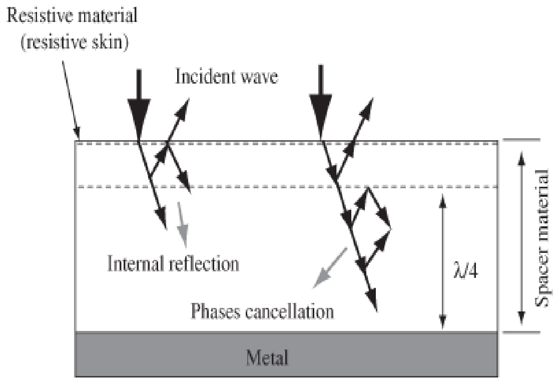
Figure 33

(f) Foam Absorber.[28] Foam absorber is used as lining of anechoic chambers for electromagnetic radiation measurements. This material typically consists of fire proof urethane foam loaded with carbon black, and cut into long pyramids. The absorber is applied to the chamber walls with the tips of the pyramids pointing inward or toward the radar. When a signal is reflected off the metal wall, it enters the base of the pyramid and bounces off the suspended carbon particles within the foam. The tapered shape of the pyramid guides signals into a confined space where they collide, resulting in destructive interference. This destructive interference is the source of signal attenuation. Other foam absorbers are available in flat sheets, using an increasing gradient of carbon loadings in different layers.

[27] Wikipedia
[28] Abid.

(g) Salisbury Screen.[29] It was first described in 1952 and was applied in ship radar cross section reduction (RCS). Salisbury screen design consists of a ground plane which is the metallic surface that needs to be concealed, a lossless dielectric of a given thickness (a quarter of the wavelength that will be absorbed) and a thin glossy screen.

Figure 34



(i) Principle.

(aa) The incident wave (which we will consider to be made up by parallel beams) is split into two (equal in intensity) waves that have the same wavelength (λ).

(ab) The first wave is reflected by the exterior surface (the thin glossy screen) while the second beam travels through the dielectric, and it is reflected by the ground plane (which is the most inner layer of the Salisbury screen)

(ac) The reflected waves interfere and cancel each other's electric fields (radar is an electromagnetic beam-microwave and IR)

(ii) Disadvantages.

(aa) One would be the fact that Salisbury screens work well only for a very narrow portion of the radar spectrum thus making it very vulnerable to multiple radar protected areas.

(ab) Another problem is the thickness of the screen itself, the radar wavelengths are between 10 cm and 1 mm, thus for a longer wavelength, the thickness gets up to 2.5 centimetres which is quite difficult to cope with (e.g. in aerospace applications).

(iii) Thus, research is being conducted for ultrathin Salisbury screens involving the Sievenpiper HIGP (high impedance ground plane), which shows remarkable improvements to the thickness of the screen.

[29] Wikipedia

(h) Jaumann Absorber.[30] A Jaumann absorber or Jaumann layer is a radar absorbent device. When first introduced in 1943, the Jaumann layer consisted of two equally-spaced reflective surfaces and a conductive ground plane. One can think of it as a generalized, multi-layered Salisbury screen as the principles are similar. Being a resonant absorber (i.e. it uses wave interfering to cancel the reflected wave), the Jaumann layer is dependent upon the λ/4 spacing between the first reflective surface and the ground plane and between the two reflective surfaces (a total of λ/4 + λ/4). Because the wave can resonate at two frequencies, the Jaumann layer produces two absorption maxima across a band of wavelengths (if using the two layers configuration). These absorbers must have all of the layers parallel to each other and the ground plane that they conceal. More elaborate Jaumann absorbers use series of dielectric surfaces that separate conductive sheets. The conductivity of those sheets increases with proximity to the ground plane.

(j) Circuit Analog Absorbers. Unlike the continuous resistive sheets of Salisbury Screen and Jaumann absorbers, conducting material deposited in geometrical patters such as dipoles, crosses, triangles etc. For such absorbers the term Circuit Analog Absorber is used as the properties of these patterns are expressed in terms of resistance, reactive capacitance and reactive inductance. Further, the design and analysis of these absorbers involve equivalent circuit techniques. The design of circuit analog absorbers is related to that of band pass or band stop surfaces. The latter are frequency selective surfaces which do not absorb radio frequency energy. The substrate material normally consists of plymide (Kapton) film. The geometric shapes have complex patterns. The electric properties of the various layers cater for different frequencies of the band. The multiple layers catering for different frequencies are spaces λ/4 to obtain broadband properties. The electrical properties vary progressively through the entire thickness of the absorber.

(k) Radar Absorbing Structures. Radar absorbing properties can be imparted to the target through mechanical design of the composite structure (generally less dense the material, lower the radar reflectivity). One such structure has a surface made of quartz glass, fibre glass or aramid fabric reinforced plastic composites. Carbon fibres are used as the backing structural material. These composites are available as aprepregs which are then moulded to the required shape/contour. In these a specific thickness of a dielectric layer separates each metal fabric layer. They are light in weight and have high strength.

Figure 35

[30] Wikipedia

IR Camouflage Materials[31]

52. Attenuation of IR Signatures. In principle, emitted IR from an object causing its signature can be curbed by the three mechanisms viz. Scattering, Absorption and Reflection; adopting one or a combination of the following methods:-

(a) Obscuration. (Discussed subsequently).

(b) Shape Tailoring. Often used in combination with surface treatment and is closely related to that followed in signature control in the microwave region.

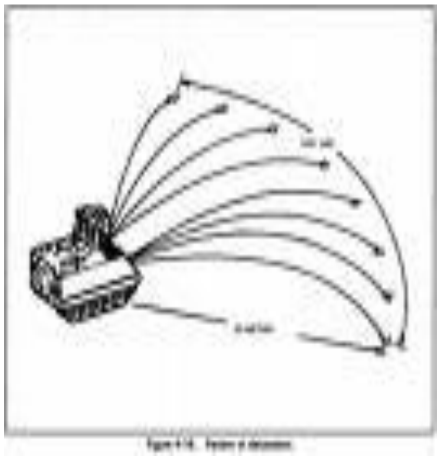
(c) Surface Treatment. (Discussed subsequently).

(d) Active Cooling. Common in designs for suppression of heat generated by an engine.

(e) Wake Cooling. Used in controlling the more direct signature contributors.

53. Obscuration.[32] It is often easier to hide a signature source than eliminate it. It is done on the assumption that the object accomplishing the obscuration will be easier to control than the object it hides. It works on the principle of scattering of visible and infrared radiation in a single stage process and is commonly referred to as either elastic or inelastic. Both result from electromagnetic radiation perturbing the electronic cloud surrounding the irradiated material. Taking advantage of the scattering phenomenon in smoke, suitable sizes of suspended particles are generated to obscure signature in the visible and IR region.

Figure 36



(a) Elastic. Also referred as Rayleigh scattering, it is the one in which radiation retains the same quantity of energy and momentum and hence keeps the frequency unchanged.

(b) Inelastic. Known as Raman scattering, the energy is exchanged with the scattering object and shifted by an equal amount to change in vibrational energy of the material through which the radiation is passing.

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[31] JV Ramana Rao – Introduction to Camouflage and Deception
[32] Abid.

54. <u>Surface Treatment.</u>[33] By way of putting coatings of different materials on the surface alters surface characteristics by modifying their reflection, self emission and directional properties, which act as a major tool for the design of camouflage in the IR region as well as in the visible and microwave regions. In IR region the main emphasis of putting such coatings on a surface, however, is to modify its reflection and self emission characteristics. A low emissive surface must have high reflectivity and vice versa. This implies:-

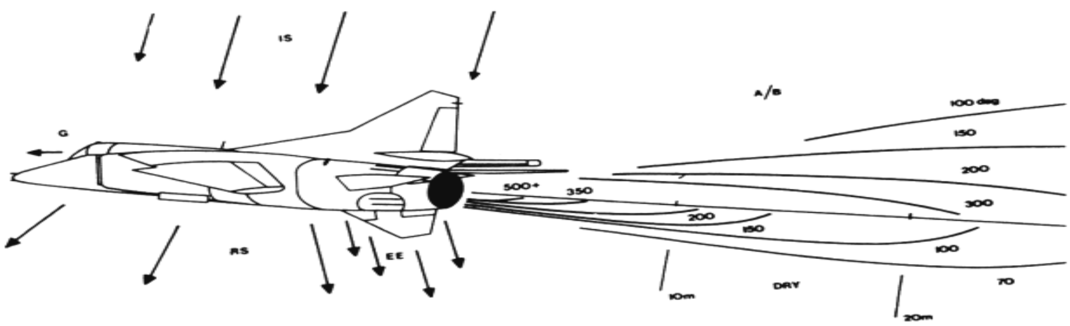
(a) When placing a high temperature object in its natural environment, low emissivity coatings may reduce self emission but still result in significant overall apparent emissions because of reflections.

(b) In near IR (NIR), reflectivities need to be dramatically higher against live foliage background. In mid and long wave (thermal) IR; reflectivities need to be high on high temperature parts so that the resulting low emissivity can reduce self emission.

(c) Required emissivity values range from 0.05 to 0.6. These low emissivities can result in high daytime solar reflections as well as high day and night ground reflections. So in some cases, as with high altitude aircraft, reflectivities must be kept low, and other means, such as active cooling techniques, must be used to control the mid IR and long wave IR emissions.

[34]

<u>Figure 37</u>



This MiG-23BM illustrates some of the components of the infrared (IR) signature of a conventional tactical aircraft. Incident sunlight (IS) is reflected and re-emitted by the airframe (RS) and canopy (G) with an intensity dependent upon the surface finish of the aircraft. The aft airframe, heated by the powerplant, emits mainly in the 4 micron band with the tailpipe radiating strongly in the 2 micron band (EE). The exhaust plume expands and cools behind the aircraft, both emitting longer wavelength (4 to 8 micron) IR and absorbing some of the shorter wavelengths emitted by the tailpipe. Note the termperature profiles (°C) for dry (DRY) and afterburning (A/B) thrust settings, the latter acting much like a 4 micron band infra-red beacon ('The Strategy of Electromagnetic Conflict' Fitts Lt Col., Peninsula Publishing, 1980.*). Tally Ho!*

[33] JV Ramana Rao – Introduction to Camouflage and Deception
[34] www.ausairpower.net

55. Coating Materials for Camouflage in IR Region.[35] Coatings offer the potential to reduce heat induced self emissions by reducing surface emissivity, and such coatings are obtained in the form of paints. Before beginning the formulation of any coating with specified IR properties, it is important to define the illuminant and conditions of illumination, the spectral response of the detector or viewer, the desired colour of the coating and the spectral distribution of the radiation to be reflected or absorbed. The next step is to select a vehicle (binder) with good heat resistance and minimal absorption in the IR bands of interest. Pigments are then selected for their emissivity (reflectivity) properties.

(a) Binder Resins.

(i) The primary requirements for resins in tailored coatings:-

(aa) First, the resin must protect the pigment and preserve its IR properties throughout the service life of the coating.

(ab) Secondly, it should exhibit very weak interaction with the electromagnetic radiation of interest.

(ii) Though most of the organic resins are free from significant absorption in the NIR region, they show strong absorption in the thermal regions. Strong absorption in the thermal IR regions can be avoided by choosing resins which do not contain common functional groups.

(iii) Examples.

(aa) Poly (Vinylidene Fluoride) Resins. They are almost transparent to and unaffected by solar radiation. They have only weak absorption in the thermal IR region in addition to having excellent weather stability.

(ab) Dimethyl Silicone Resins. They have emittance values lower than those of fully organic resins and have been used for low emittance coatings.

(iv) Absorption by resins can also be reduced by the selection of pigments which because of their refractive indices and particle sizes scatter light effectively in the band where resins absorb. This technique can be used to great advantage in the thermal IR region.

(v) In addition, leafing metallic pigments which form a practically continuous film reduce the penetration on incident radiation and absorption by the underlying resins.

[35] JV Ramana Rao – Introduction to Camouflage and Deception

(b) Pigments. In conventional paints the main role of the pigment is to provide opacity and colour through control of reflectivity of the paint with its right index of refraction as compared to the binder resins. However, pigments exert their principal influence on the optical and NIR properties of coatings. Pigments used in the IR region are selected based on their emissivities, scattering and reflectance properties in this region.

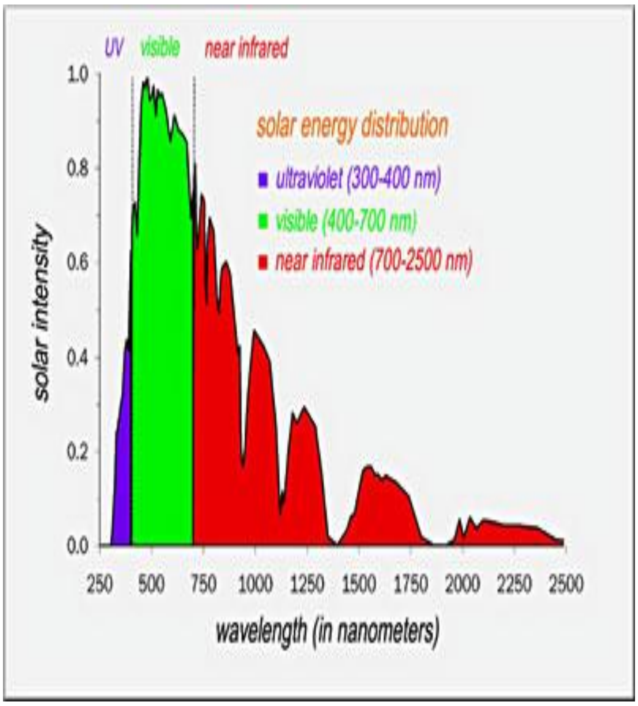
(i) Pigments and Coatings for Near IR.[36] A wide variety of useful NIR properties are obtained when pigments are dispersed in film.

(aa) Titanium dioxide pigments reflect NIR radiation very well as indicated by their high value of scattering power (particle of size 10 µm reflects well between 0.8 and 2.3 µm with very little or no visual effect of the coating).

(ab) Pigments which absorb in the visible region but are transparent in the NIR region can be considered to be extenders so far as NIR radiation is concerned, that is, they can be used to modify the visual appearance of the paint without affecting the IR properties.

(ac) Organic pigments such as perylene black, phthalocyanine blues and greens and carbazole dioxazine violet are useful for this purpose.

Graph 3



(ad) In painting military objects which protect against systems which use the NIR wave bands and operate in low light conditions, it should be understood that the term 'Low Reflecting IR Paint' generally means a paint that is highly absorbing in the NIR (with consequently higher signature in Thermal IR on exposure to sunlight).

(ae) Likewise, the term 'IR Reflecting Paint' refers to highly reflecting NIR paint (with a consequently lower thermal signature on exposure to sunlight).

[36] JV Ramana Rao – Introduction to Camouflage and Deception

(ii) Pigment and Coating for Thermal IR.[37] Coatings using conventional pigments and working on scattering principles are ruled out for this region because of the difficulty in getting a balance between the size of the pigment particles required to scatter in this region and overall desired smoothness.

Figure 38

(aa) Inorganic pigments show strong and broad absorption bands. For example, carbonate absorbs about 7 µm, silicate at about 9 µm and oxides between 9 and 30 µm. Organic pigments such as the perylene blacks, phthalocyanne blue and green, and carbazole dioaxazine violet show strong sharp absorption bands throughout the thermal IR, but principally between 6 and 11 µm.

(ab) The properties of coatings based on these pigments are likely to be influenced by the pigments used and are wavelength dependent. Grey body approximation for these coatings is likely to lead to considerable error.

(ac) Therefore, metallic pigments in the form of flakes are generally used to achieve both emissivity and reflectance coatings in the thermal IR region. Metals show low emissivity because they contain free electrons that provide for high refractive indices over broad bands.

(ad) Less reflectivity and more spectral shaping can be accomplished by choosing lower conductivity materials. Semiconductors show less conductivity than metals. Their lower electron density causes semiconductors to have a high refractive index, with corresponding high reflectivity at longer wavelengths and transparency at lower wavelengths with reduced refractive index and extinction coefficients.

(ae) An alternate method of hiding thermal signature of a vehicle is to place a thermal barrier directly between the heat producing object and the sensor. Fabrics from both inorganic and organic fibres such as polymides, polybenzimidazole, polymideimide and aluminosilicate have been reported for this application. The thermal protective performance of these fabrics is related to their thickness, density, air permeability and moisture content.

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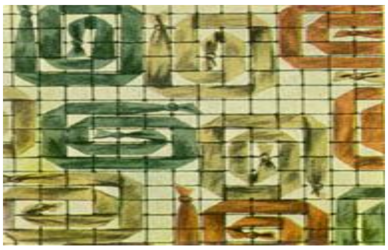
[37] JV Ramana Rao – Introduction to Camouflage and Deception

Coating Materials for Camouflage in the Visible Region[38]

56. Camouflage in the visible region is to confuse the human eye, and it can be accomplished by three methods, viz., Hiding, Blending and Deception. In all of these materials play a central role.

(a) Nets.[39] Apart from providing visual camouflage, camouflage nets should also provide camouflage from infrared cameras, thermal imaging detectors and radar detection. Camouflage should therefore be provided in the infrared, thermal imaging, extremely high and super high frequency radar beam range. This means that it should not be possible to recognize or identify the objects to be camouflaged by active video receivers in the 0.7-1.8 µm range or by passive video receivers in the 3-5 µm and 8-14 µm range. Various camouflage nets are already known for this purpose. It is now known that in the atmospheric windows around 26-40 and 92-96 GHz natural objects, such as a grass and plants, behave like black body radiators with an emission level of almost one, whereas military objects, such as armoured vehicles, lorries, etc. made of metal have an emission level of approximately zero and therefore a remission level of approximately one. Therefore the latter are ideal reflectors, with one part of the beam being directed, while one part provides a diffused reflection. This means that with radiometric measurements from above the object to be camouflaged, e.g. a military object, reflects thermal radiation into the sky with a temperature of 30K at 35 GHz and 100K at 94 GHz, whereas the environment radiates as a black body radiator with ambient temperature. The military object therefore behaves like a very cold target in a warm environment, with the temperature contrast being between 240K and 280K. In this way it can be detected as a cold body with a microwave radiometer. When the sky is overcast and it is still high enough for armoured vehicles to be located with a passive microwave seeker head for the final phase guidance of shells and missiles.

Figure 39



Twine net garnished.
Mainly effective against long-range observation

Camouflage Net
Protecting against visual, as well as modern infrared, near infrared and radar threats

38 JV Ramana Rao – Introduction to Camouflage and Deception
39 US Patent and Trademark Office (Camouflage Net)

(b) Aqueous Foam.[40] Air is mechanically entrained in a dyed or coloured, aqueous solution comprising surfactant, poly(oxyalkylene) polyisocyanate prepolymer and the reaction product of said prepolymer and one or more isocyanate-reactive dyes, the poly(oxyalkylene) portion of said prepolymer containing sufficient oxyethylene units to render the prepolymer and the reaction product water-soluble and hydrophilic, to form a dyed or coloured, fluid, aqueous air foam which is sprayed or otherwise applied to exposed surface of a substrate, e.g. a sanitary landfill, the applied foam gelling or increasing in viscosity, due to the polymerization, e.g., by reaction with water or polyamine, of the prepolymer and the reaction product, to form a dyed or coloured, poly(oxyalkylene) polyurea polymer, forming a persistent, dyed or coloured, gelled or viscous air foam in the form of a coating on the exposed surface, thus sealing or otherwise protecting or controlling the substrate and colouring the substrate making it more visible, decorative, or less visible, thereby camouflaging the substrate. The advantages are:-

(i) Easily produced/removed onsite(water being a presupposition).

(ii) Can cover large areas.

(iii) Can be pigmented so that the texture matches the background; thereby enhancing flexibility.

(iv) Quick to dispense.

(d) Smoke. When choosing smoke material for use in battle it must exhibit an acceptable screening capability both in the visible and the IR spectrum. To avoid being too strong the smoke should as far as possible coincide with the surroundings in the two spectra. In addition to providing a screen it should be able to:-

(i) Maintain, with a large degree of probability (>90%) in a wind strength of up to 8 m/s across the direction of attack, an effective smoke screen between incoming rocket/laser designator and the gun, in the last phase of the flight time of the rocket, approx. 10-15 s.

(ii) Should protect against laser-guided, TV-guided and advanced picture-forming IR-target seekers.

(iii) Used for training in times of peace thereby requiring a smoke material which is environmentally acceptable.

(iv) The smoke should be least apparent in the visible and infra-red wave spectrum.

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[40] J. W. Bates- New Uses for Highly Miscible Liquid Polymeric Colourants in the Manufacture of Coloured Urethane Systems
Also See - **Vehicle Carried System for Camouflage with Foam** (discussed subsequently)

(c) Paints. A pigmented liquid composition which is converted to an opaque solid film after application as a thin layer, is essential for the protection and decoration as a thin layer, is essential for the protection and decoration of the majority of manufactured metallic goods and architectural and industrial structures which characterise our complex material civilisation.

(i) The foremost requirement of paint for camouflage applications are:-

(aa) Match optical properties with the background.

(ab) Should be stable.

(ac) Should be corrosion resistant.

(ad) Should be non glossy.

(ii) Paints may have one to three separate layer types and be in the form of primer, undercoat and topcoat.

(aa) Primer. The main purpose of the primer is to provide a mechanism for each successive layer to adhere to the underlying surface and to a certain extent to serve against corrosion of the metal.

(ab) Under Coat. Contains a primary pigment designed to control spectral reflectivity. It may also be the top coat if one not applied. It is the most important constituent.

Table 1

Pigment (filler)	Primary material used to impart colour; remains insoluble, provides:- Protection, Hardness, Weatherability and Roughness.
Dyestuff	Secondary material used to impart colour; soluble in solvents and/or binder, transparent in their coats; limited uses.
Binder (Polymer)	Holds pigment particles together to substrate; transparent to visible light.
Solvents	Provide application mobility, evaporate.
Additives	Driers, wetting antisag, flattening and similar agents.

(ac) Top Coat. A transparent top coat may be used to control surface roughness, provide abrasion resistance and contamination protection.

(d) Antireflective Coatings.[41] An object otherwise well camouflaged may be detected due to the glare caused by the reflection of the visible portion.

(i) The underlying principle for a material to be antireflective on a substrate, for example, glass is

$$n_2 = \sqrt{(n_1 n_2)}$$

Where;
n_1 = Refractive index of glass (1.5)
n_2 = Refractive index of material
n_3 = Refractive index of air (1)

The thickness (d) of the coating should follow the relation:-

$d = ƛ/4n_2$ where ƛ is the wavelength of light.

(ii) Some materials showing antireflective characteristics on glass are thorium tetrafouride, cerium trifouride, magnesium oxide and titanium oxide. Antireflective coatings from these materials can be obtained by depositing single layer of a substance or multiple layers of more than one substance of thickness 'd'.

(iii) The coating from these materials is obtained by depositing single layer of a substance or multiple layer of more than one substance of thickness 'd'. They can be applied by:-

(aa) Plasma Vapour Deposition.
(ab) Vacuum Deposition.
(ac) Chemical Vapour Deposition.
(ad) Spray Pyrolytic.
(ae) Dip Coating/ Sol Gel.

Figure 40

[41] JV Ramana Rao – Introduction to Camouflage and Deception

<u>Multi-Functional Appliqué for Corrosion Control</u>[42]

57. Despite extensive research to improve the performance of paint technology, corrosion has risen substantially. Adhesively-backed polymer films are being evaluated as an alternative to paint for corrosion control. This paradigm shift presents designers of military equipment with a new tool to manage the interface between equipment and its operating environment. While a wide variety of corrosion-resistant alloys have been developed, the up-front costs for materials and manufacturing are often unacceptably high. Even where exotic alloys are utilised the equipment is normally painted for other reasons.

58. <u>Necessity.</u> In addition to the obvious drawbacks due to corrosion:-

(a) The proliferation of advanced sensors is creating requirements for military systems unachievable by today's paint systems.

(b) Rapid deployment initiatives will benefit from the ability to rapidly re-configure equipment to optimize its performance in deployed environments (e.g., change from desert sand to forest green finishes).

(c) The changing force structure will ultimately limit the ability of the military to do in-service maintenance of paint systems.

(d) The need to maximize the service readiness of military equipment limits time available for depot level corrosion maintenance activities.

(e) The emergence of environmental constraints that are increasingly limiting paint manufacturers to low volatile organic carbon (VOC) formulations that may not be capable of achieving demanding specifications.

59. <u>Paint-Replacement Appliqué.</u> An appliqué is a permeation-resistant, adhesively-backed plastic film that can be field applied in a 'peel and stick' operation. In its simplest form, the film may be clear or pre-pigmented to meet a military colour specification and surface finish. In an advanced form the appliqué may be a single or multi-layer film that is patterned, coated, textured, metallised, or otherwise modified to impart some advanced functionality. Features that a peel-and-stick appliqué offer over a spray application technology include:-

(a) The improved quality of a precision manufactured film as a corrosion barrier *vis-a-vis* painted surfaces, i.e., a pinhole-free film.

[42] Dr. John M. Brupbacher - Multi-Functional Appliqué for Corrosion Control

(b) The ability to impart features and functions in precision manufacturing not readily achievable with spray coating technologies (e.g., imbedded sensors, textured surfaces, etc.) facilitating better camouflage.

(c) Environmentally-friendly application and removal methodology.

(d) A simple, applicator-friendly application methodology.

60. Obstacles to Appliqué Implementation. Implementing a new technology for corrosion control, such as the appliqué concept, will require adequately addressing a number of real and perceived issues. Issues that will have to be resolved include:

(a) Application of two dimensional (2D) film to complex curvature surfaces.

(b) Protocols and durability of seams and joints.

(c) The conflict between field durability and the peel-and-stick vision.

(d) Availability of adhesive systems that are mil-fluid compatible and can provide acceptable strength and failure modes under demanding military thermal (e.g., -55 to 175◦C) and operational environments.

61. Rationale for Multi-Functional Appliqué. Given that paint is a proven, yet effective, corrosion control technology, system designers and maintenance engineers will be reluctant to adopt appliqué technology without proven corrosion-control and attractive life-cycle cost advantages. Acquiring this data will require a considerable investment in field trials, personnel and equipment over an extensive period. Appliqué designers are then presented with one of two strategies:-

(a) Seek a low-cost appliqué.

(b) Pursue multi-functional appliqué.

62. The low cost strategy pushes designers away from fluoropolymers to unproven, low-cost resin variants. This is generally at odds with the primary mission of finding a superior alternative to paint systems for corrosion control. The alternative is to identify applications with a demanding corrosion environment but with complementary system requirements that cannot be achieved by today's paint formulation or processing techniques.

63. Multi-functional appliqué based on fluoropolymer resins with proven corrosion control are the most promising route to moving forward with an appliqué-based paint replacement initiative.

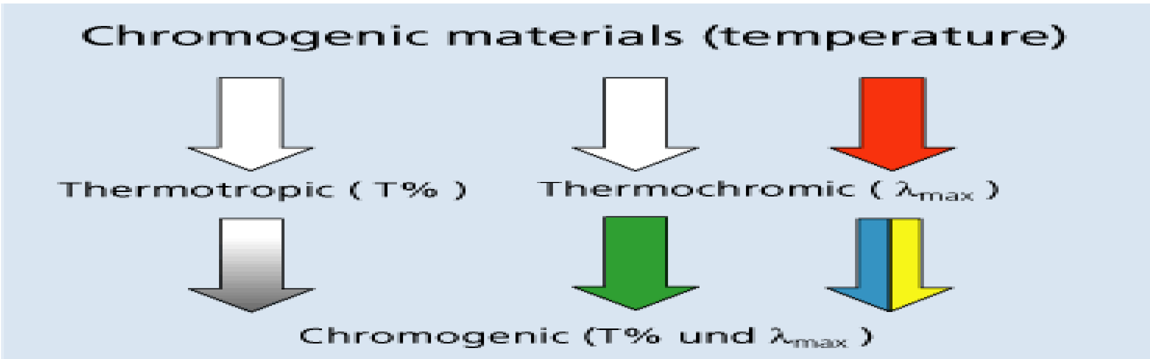
Modern Trends in Camouflage Materials

64. Chromogenic Materials.[43] Some existing and proven technologies in other areas offer opportunities for adaptive signature control. For example, passive and active technologies available for visible and infrared applications in solar energy and display device areas could be used in camouflage to better match background conditions over the long term. Adaptive material (coatings) can be grouped into categories named after the mechanism responsible for the adaption process. Materials whose optical properties are subject to change by the application of external stimuli are called chromogenic. Some of the major chromogenic materials are:-

(a) Thermochromic. Optical properties are reversible under the influence of temperature. Example – Cholestric liquid crystals.

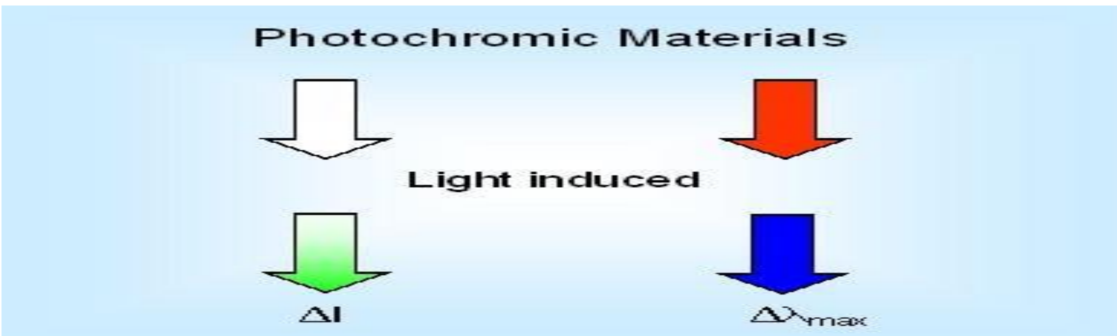
(b) Electrochromic. Optical properties are reversible under the influence of an electric field. Example – Viologenes, conducting polymers.

Figure 41



(c) Photochromic. Optical properties are reversible under the influence of incident radiation flux. Example – Inorganic complexes, organic dyes and conducting polymers.

Figure 42



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[43] JV Ramana Rao – Introduction to Camouflage and Deception

65. Luminescent Materials.[44] One of the conducting polymers, viz., polyphenylene vinylene (PPV), and showing very good luminescent properties associated with its processing advantage of being a polymer, looks like a good replacement for liquid crystals.

(a) Passive Camouflage. PPV would be used similar to camouflage paint today. It could however also be tailored to form part of an active system; a sheet of PPV could be modified to emit in specific colours as required for a particular application and attached to an intelligent processing and environment sensing system.

(b) Active Camouflage. Possible applications include:-

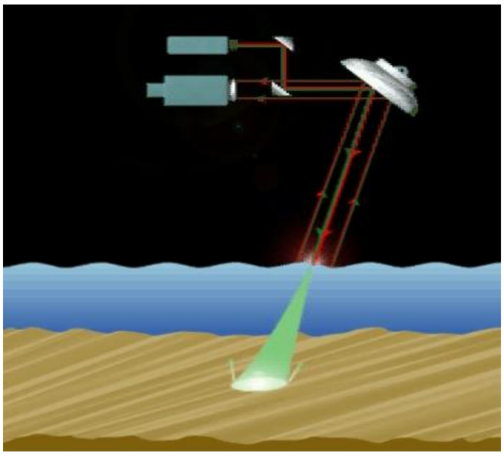
(i) Camouflage sheets to cover vehicles or facilities.

(ii) Optical stealth coatings or foils for vehicles applied to outer hull of land vehicles, aircraft and even submarines and ships.

(iii) Aircraft Application. The coatings on the underside would reproduce what the platforms sensors see above.

(iv) Submarine Application. This material promises the means to defeat a new mode in detection in anti submarine warfare – The Blue-Green Laser.

Figure 43



Blue-Green Laser Airborne

and

Satellite LIDAR

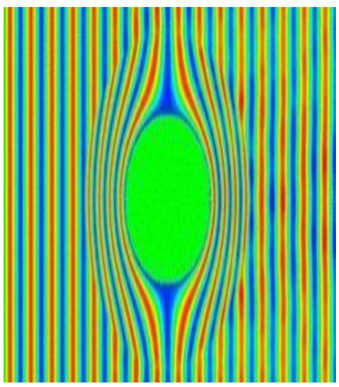
[44] JV Ramana Rao – Introduction to Camouflage and Deception

66. Polymers and Composites.[45] The prime focus of materials research in the polymer compounds and composites field are passive in application, many of which involve substitution of metals in existing applications. The driving force for advances in this area has been the composite paradigm (anisotropic design) and computer aided design, manufacture and modelling, and the underpinning detailed molecular level understanding from advances characterisation and measurement facilities. Polymer composites which comprise high performance polymeric matrix have replaced metals and metal alloys in many structural applications (especially space and maritime). Two classes of new polymers, i.e., liquid crystalline polymer and conducting polymer, poses unique combination of mechanical, electrical, optical, etc. properties, and an ample scope for tailoring these properties through molecular design. This provides an excellent opportunity to develop perspective multispectral camouflage materials, both as surface appliqué and structural materials in form of composites for strategic military objects.

67. Metamaterials.[46] Metamaterials may be best known as a possible means of “cloaking” to produce an illusion of invisibility, somewhat like the low-reflectivity coatings that help stealth fighter jets evade radar. Vibrating particles in these metafilms cause incoming electromagnetic energy to behave in unique ways. Metamaterials, also known as left-handed materials, are exotic, artificially created materials that provide optical properties not found in natural materials. Natural materials refract light or electromagnetic radiation, to the right of the incident beam at different angles and speeds. However, metamaterials make it possible to refract light to the left, or at a negative angle. This backward-bending characteristic provides scientists the ability to control light similar to the way they use semiconductors to control electricity, which opens a wide range of potential applications.

68. Acoustic Cloaking.[47] Metamaterials, materials defined by their unusual man-made cellular structure, can be designed to produce an acoustic cloak -- a cloak that can make objects impervious to sound waves, literally diverting sound waves around an object. To realise the cloak physically requires calculations as to how metamaterials are constructed with sonic crystals, solid cylinders in a periodic array that can scatter sound waves, could be used in a multilayered structure to divert sound completely around an object. This has tremendous scope for naval applications to avoid Sonar.

Figure 44



[45] JV Ramana Rao – Introduction to Camouflage and Deception
[46] (US) National Institute of Standards and Technology
[47] www.sciencedaily.com

69. Phased Array Optics.[48] Phased array optics is a technology that will produce three dimensional views of objects and scenery using only two dimensional displays.

(a) They are based on the theory of diffraction from physical optics. Patterns of light waves travelling beyond an aperture (such as a window) are entirely determined by the amplitude and phase distribution of light at the surface of the aperture. By producing light with the right phase and brightness distribution across a two dimensional surface, we can reproduce the same light waves that would emanate from a three dimensional scene behind the surface.

(b) Phased arrays and holography are both methods of wave front reconstruction, and both can produce three dimensional images. However they differ in some important ways:-

(i) Holography avoids the computational requirement of arrays with a simple and elegant solution.

(ii) Holographic recording produces phase modulation that is too coarse for unambiguous wave reconstruction.

(iii) When you shine a laser on a hologram you will always get three beams out: the reconstructed object beam, the (unwanted) conjugate beam, and the laser beam itself. Phased arrays modulate phase and amplitude at half wavelength intervals. This is close enough to generate only one interference maximum, which contains the reconstructed beam and nothing else.

(c) Active invisibility means an array would acquire and synthesize contiguous scenery in real time. This could be accomplished with a system a few millimeters thick. The interior layer of our hypothetical "invisibility suit" consists of photo sensors comparable to a human retina. The exterior is a phased array with phase shifters of extra close spacing and high refractive index. Half of the shifters are dedicated to image production, while the other half transmit light through to the photosensitive layer. The transmitting shifters are adjusted to form a multitude of focussed "fly's eye" images on the photosensitive layer. The system is thus able to both produce and view scenery from all angles at the same time. A powerful computer network would manage the scenery synthesis and other details, such as how suit movement affected phase relationships.

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[48] Brian Wowk –Phased Array Optics

70. Nanotechnology.

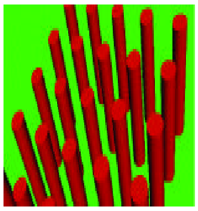
(a) Mercedes Experiments on Car Paints.[49] A Mercedes Benz research paper obtained by Polymer, Paint, and Colour Journal has flagged up a groundbreaking new coating technology that is currently being developed by its specialists. "Nanotechnology - Inners Values (the Vast Potential of nanotechnology in the Automobile Industry) says: "By changing an electrical field, the alignment of the pigments in chameleon-effect nanopaints can be altered. As a result, the paint changes its colour depending on the voltage applied." Besides offering protection against potentially damaging mechanical processes, the silicon-organic nanopaints can also help in the fight against corrosion. According to Mercedes researchers these paints could build a barrier safeguarding against water vapour and harmful chemicals.

(b) Photonic Crystals.[50] Photonic crystals are micro-structured materials in which the dielectric constant (equal to the square of the index of refraction at optical wavelengths) is periodically modulated on a length scale comparable to the desired wavelength of the electromagnetic radiation. Multiple interference between optical waves scattered from each unit cell results in a range of frequencies that do not propagate in the structure. At these frequencies, the light is strongly reflected from the surface, while at other frequencies light is transmitted.

(i) For example, highly reflective surfaces are routinely constructed from simple layered dielectric structures with alternating layers of high and low refractive indices.

(ii) One-dimensional photonic crystals have long been used as anti-reflection coatings or as wavelength-selective mirrors which do not reflect heat. In two dimensions, one can construct a periodic variation in index of refraction by assembling an array of cylinders.

Figure 45



(iii) Defects may be created inside photonic crystals by removing or adding dielectric material, thereby allowing the light propagation to be modified.

(iv) Photonic crystals with and without defects have been demonstrated at microwave frequencies, but fabricating similar, visible-wave length photonic crystals would require state-of-the-art nanofabrication techniques.

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[49] internationalnewsservices.com
[50] Dr. Bob D. Guenther – Engineering: The Future of Nanophotonics

(c) Nissan's Paramagnetic Paint.[51] They have developed a "paramagnetic" paint coating, which is a unique polymer layer that features iron oxide particles that are applied to the vehicle's body. When an electric current is applied to the polymer layer, the human eye then interprets the crystals in the polymer as different colours. Depending on the level of current and the spacing of the crystals, a wide range of colours can be selected by the driver. A steady current is needed to maintain the colour effect, thus the paramagnetic paint doesn't work when the vehicle is turned off and hence the vehicle switches back to a default white colour.

Figure 46

(d) Smart Paints.[52] Experts are trying to embed microscopic electromechanical machines in paint that could detect and heal cracks and corrosion in the bodies of combat vehicles, as well as give vehicles the chameleon-like quality of rapidly altering camouflage to blend in with changing operating environments. These "smart" paints should be able to alert maintenance technicians of potential problems with the coating, in addition to modifying their physical characteristics on command. "Rather than paints, we are talking about coatings, which could be electroplated, or put on with physical vapour deposition qualities. We are talking about more things than paints. They could be metallic or have other qualities."[53] Vehicle operators might quickly change the camouflage paint scheme on vehicles with "smart" coatings with an electrical impulse. "What we hope this coating can do is amazing. We're also looking at making it seem invisible."[54]

(e) Carbon Nanotubes (CNT). Polymer matrices containing CNTs is a very active area of research and development. Polymers which are normally electrically insulating but have other advantages of being flexible, have low density, and are easily formed, can be combined with CNTs, which have excellent electrical conductivity, extreme mechanical strength, and high thermal conductivity. By combining these two materials, a nanocomposite with extremely useful properties can be obtained. The most useful application areas are electromagnetic shielding, microwave absorption, ballistic protection, and chemical sensor clothing.

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[51] www.trendhunter.com
[52] slashdot.org
[53] Joe Agento, program integration manager at the TACOM-ARDEC Industrial Ecology Centre at Picatinny Arsenal.

[54] Laura Battista, environmental engineer at the Industrial Ecology Centre

(f) Non-Chromate Corrosion Inhibitors.[55] Until now, no chromate-free corrosion inhibitor has performed as well as heavily loaded chromated primers. Recently nanoparticle based organic corrosion inhibitors that are highly effective and chromate-free have been developed. These nanoparticles have organic corrosion inhibitors anchored to the surface that are triggered to release by the corrosion process. While anchored, the corrosion inhibitors are non-leachable, but when released they migrate to arrest corrosion at the metal surface. These materials provide excellent corrosion resistance in epoxy primers on high strength aluminium alloys. The nanoparticles performed as well as chromate materials in both a 3,000 hour salt fog tests and the even more difficult 1000 hour filiform corrosion tests.

(g) Nanotech in Materials.

(i) Nanotechnology enables high strength, durable, sensoric and active materials.
(ii) Adaptive Suits. Switchable fabrics for improved thermal control, switchable camouflage.
(iii) Lightweight: high strength nanocomposite plastics are expected to replace metal and thus reduce weight and radar signature.
(iv) Adaptive Structures. Active structures that adapt to changing conditions such as adaptive camouflage, suspension, flexible/rigid etc.
(v) Stealth. Radar absorption coatings etc.
(vi) Power Signature. Hybrid, electrical/combustion, powering, driven by civil automotive, reduces consumption and signature.

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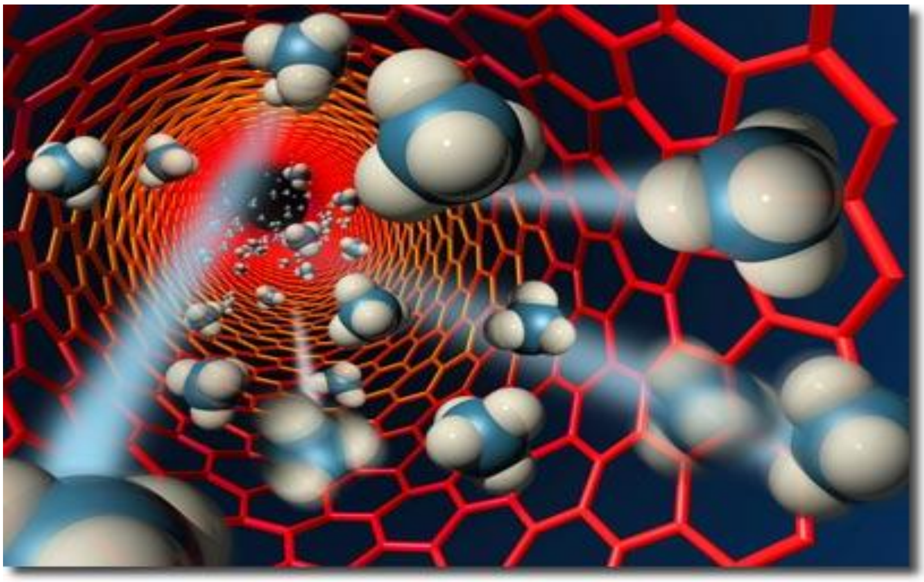
Figure 47



[55] www.tda.com

MODERN CAMOUFLAGE TECHNIQUES

Thermal and Visual Camouflage System[56]

71. Provides camouflage in both the visual spectrum and the infrared spectrum by emulating the infrared radiation of an object's background and the visible radiation of an object's background, effectively cloaking the object from detection.

72. Initially, the temperature and colour of the background against which an object appears is determined. The external surface of the object, or alternatively a shield around the object, is then heated or cooled using thermoelectric modules that convert electrical energy into a temperature gradient.

73. The ability of the modules to be either cooled or heated permits the output of the modules to be altered to match the temperature of an object's background. In combination with these thermocouples, the invention utilises choleric liquid crystals to alter the visible colour of an object. Since the visible colour of choleric liquid crystals can be changed with temperature, the heating and cooling ability of the thermocouples can be used to adjust the colour of the liquid crystals to match the object's background colour.

74. The system uses a system of thermocouples and a conductive shield having a first side and a second side, wherein said thermocromatic element is attached to the first side and said thermocouple is attached to the second side of said shield.

Photo Stealth Technology[57]

75. This technology is anti visual and can only work in specific terrains, due to the photo-realistic scene patterns; once an item has finished a tour of duty it can be re-wrapped and sent to another specific location. The camouflage is so realistic that any soldier or equipment can virtually disappear in the battlefield environment.

Figure 48

An example showing how 'Photo-Stealth' is used rendering an aircraft invisible over the woodern pattern

[56] US Patent and Trademark Office (Thermal and Visual Camouflage Systems)

[57] www.military-heat.com
Military Wraps Research & Development, Inc.

Low Thermal Signature Camouflage Garnish[58]

76. It uses a garnish of tufts of filaments or strips attached to camouflage material, particularly camouflage material for use on mobile equipment, vehicles and personnel.

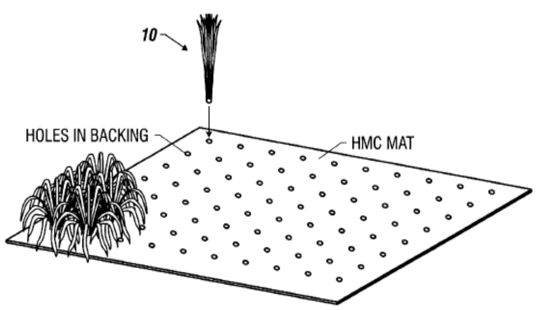
77. The garnish or tuft is formed from a sheet of flexible, low emissivity material that has been cut into filaments or strips adhesively attached along one uncut longitudinal strip edge portion of the sheet.

78. The tuft is formed by rolling the strip edge portion longitudinally around one part of a tuft retaining anchor, to form a rolled, adhesive-bound segment attached to the tuft part. When the rolled strips or filaments are so bound about the tuft retaining anchor part, a tuft is formed there from. When all the tuft retaining anchor parts are assembled, the tuft retaining anchor and tuft together constitute the garnish.

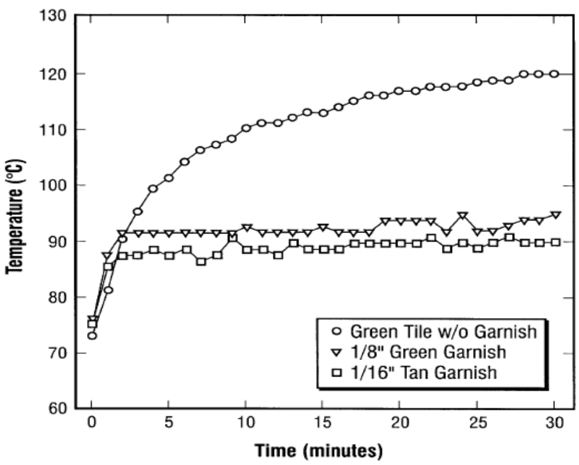
79. A plurality of garnishes is attached to a base camouflage material on, e.g., mobile equipment, vehicles and personnel. The garnishes are preferably removably attached, to enable the colour and other properties of the tuft to be varied in accordance with the surroundings in which the camouflage is to be affected.

80. The tuft effectively absorbs and then dissipates heat by inducing air currents around the camouflaged object. The heat absorbed and dissipated otherwise would have been absorbed either by the base camouflage material or the device sought to be camouflaged, with a concomitant increase in the infrared signature of that device. This absorption and dissipation of heat is particularly effective when conditions of bright sunshine and calm or still conditions exist, especially in the early morning hours.

Figure 49



Graph 4



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[58] US Patent and Trademark Office (Low Thermal Signature Camouflage Garnish)

Vehicle Carried System for Camouflage with Foam[59]

81. Water based generation of large quantities of foam to be placed in containers/ bags and externally attached to the vehicle. The system can just as well be used for ground camouflage which includes road and runway camouflage (especially makeshift/ temporary ones).

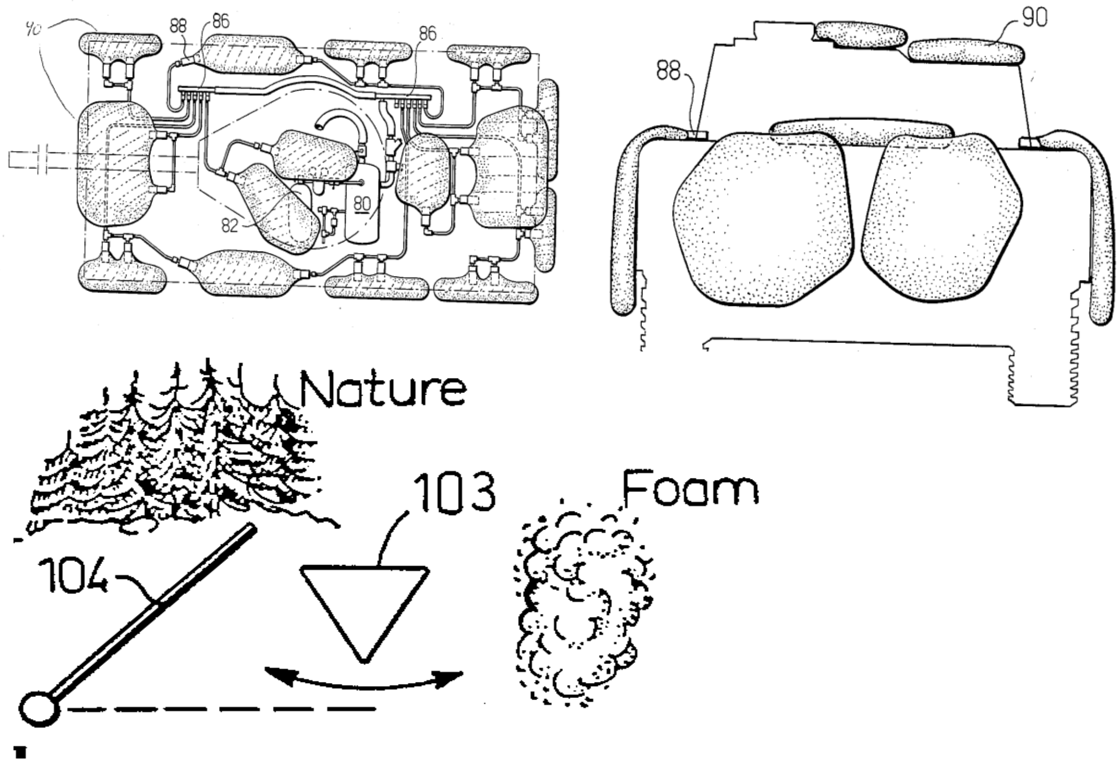
82. It offers the advantage of flexibility in the colour of the foam being used thereby enhancing the camouflage characteristic.

83. The system carries an onboard foam generator and presupposes the availability of water.

84. The colouring generator works on the feedback of the sensors as to the natural camouflage requirements.

85. The system not only provides good visual camouflage but also their form is so selected to provide good camouflage from microwaves, IR and thermal radiation. And the bags must be sufficiently thick to permit attenuation of IR and Microwaves. The outer surface is made of a cloth fibre such that it is permeable to air but not to foam. Depending on the stability of the composition the foam can last up to 48 hours.

Figure 50



59 US Patent and Trademark Office (Vehicle Carried System for Camouflage with Foam)

Multi-Perspective Background Simulation Cloaking Process and Apparatus[60]

86. The apparatus uses thousands of light receiving segmented pixels and sending segmented pixels are affixed to the surface of the object to be concealed.

87. Each receiving segmented pixel receives coloured light from the background of the object. Each receiving segmented pixel has a lens such that the light incident upon it is segmented to form focal points along a focal curve (or plane) according to the light's incident trajectory.

There are two embodiments for reproduction:--

(a) Fibre Optics. In a first embodiment, this incident light is channelled by fibre optics to the side of the object which is opposite to each respective incident light segment. The light which was incident on a first side of the object travelling at a series of respective trajectories is thus redirected and exits on at least one second side of the object according to its original incident trajectory.

(b) Photo Diodes. In a second embodiment, this incident light is segmented according to trajectory, and detected electronically by photo diodes. It is then electronically reproduced on at least one second side of the object by arrayed LEDs. In this manor, incident light is reproduced as exiting light which mimics trajectory, colour, and intensity such that an observer can "see through" the object to the background.

88. In both embodiments, this process is repeated many times, in segmented pixel arrays, such that an observer looking at the object from any perspective actually "sees the background" of the object corresponding to the observer's perspective.

The object has thus been rendered "invisible" to the observer.

Figure 51

Note

This figure is only depicted to demonstrate the effect and is not how the product is intended to be fabricated.

It depicts
Retroreflective Projection Technology (RPT) discussed next.

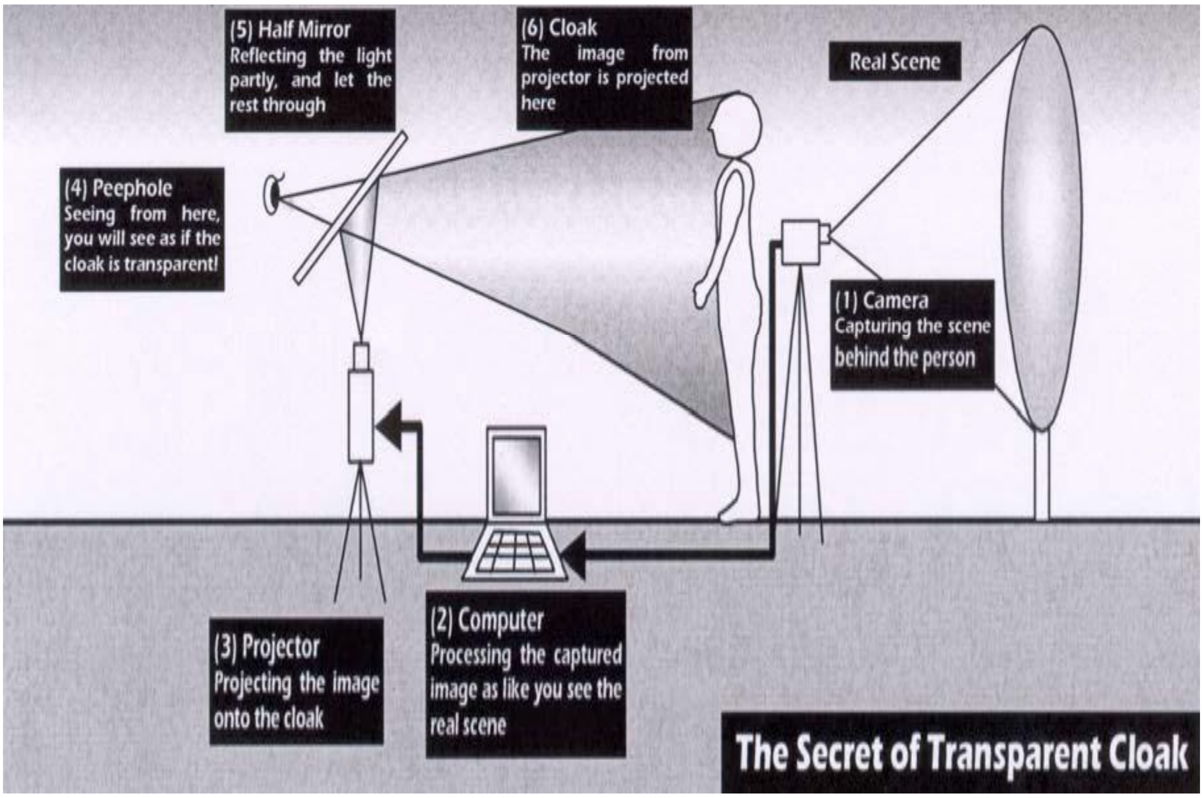
RPT with projection on a retro-reflective cloak

[60] US Patent and Trademark Office (Multi-Perspective Background Simulation Cloaking Process and Apparatus)

Retroreflective Projection Technology (RPT) [61]

89. It involves a system for active camouflage in which a camera and projector are set up in front of the eye of an observer.

Figure 52



90. The image is projected onto a retro-reflective material. From the eye of the observer, the retroreflective material appears invisible.

[61] Kent W. McKee and David W. Tack - Active Camouflage for Infantry Headwear Applications. Product developed by Tachi Laboratory at the University of Tokyo

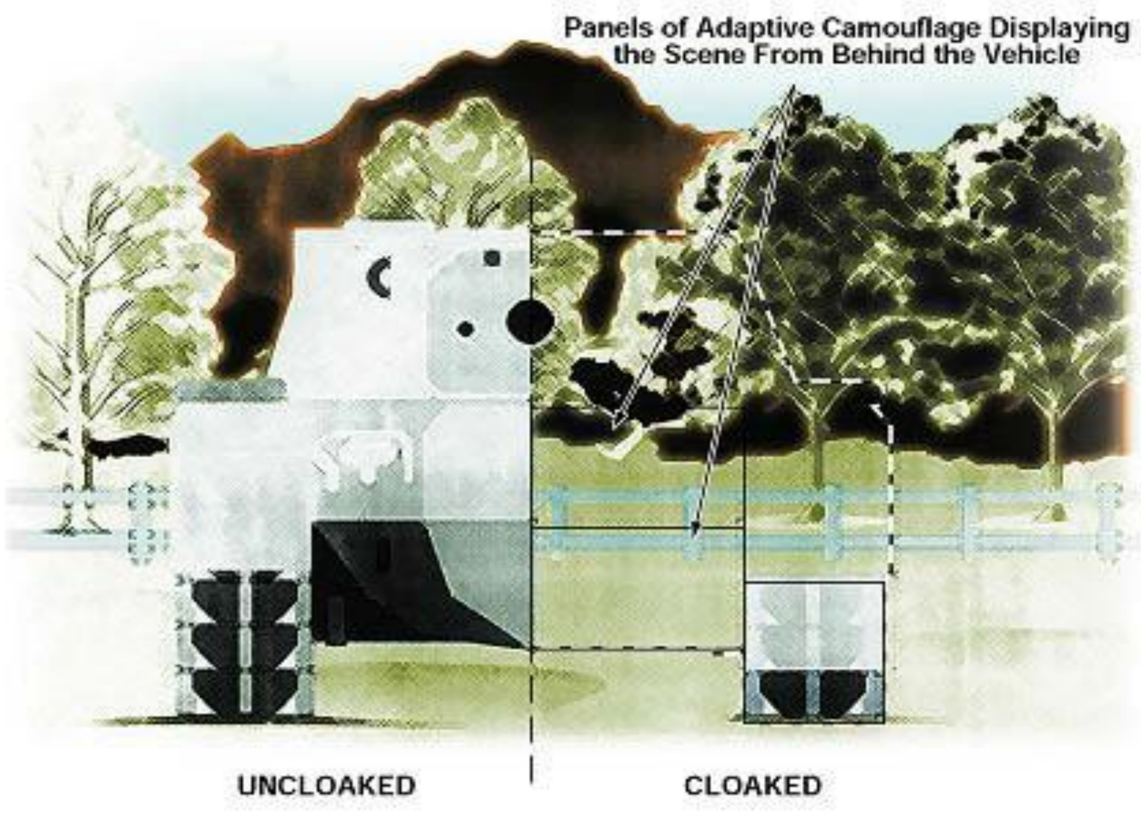
Cloaking Tanks[62]

91. NASA's Jet Propulsion Laboratory has proposed lightweight optoelectronic systems that use image sensors and display panels (Moynihan and Langevin, 2000) that display the background image of terrain behind the object being camouflaged.

92. The display panels would be sized and configured so that they could be used to cloak a variety of objects. The volume of a typical image sensor would be less than about 1 cubic inch (16 cubic cm). A system to completely cloak an object 10 m long by 3 m high by 5 m wide would weigh less than 100 lb (45 kg).

If the object to be cloaked were a vehicle, then the adaptive camouflage system could potentially be operated on power provided by the vehicle electrical system.

Figure 53



93. Project Chameleo.[63] The system involves a device designed to conceal an object by placing a thin "video screen" between the observer and the object being concealed". Plans allow its application to both stationary/moving vehicles and soldiers.

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[62] Kent W. McKee and David W. Tack - Active Camouflage for Infantry Headwear Applications.
[63] Richard Schowengerdt - "optoelectronically" controlled camouflage - Project Chameleo.

Light-Weight Camouflage Screen System[64]

Figure 54

94. The Light-Weight Camouflage Screen System [LCSS] is a camouflage net that provides protection in areas where there is no large convenient overhead cover, such as unploughed fields, rocky areas, grasslands, and other wide-open spaces.

95. The LCSS is a modular system consisting of a hexagon screen, a diamond-shaped screen, a support system, and a repair kit. Any number of screens can be joined together to cover a designated object or area.

96. They are radar scattering or radar transparent. The radar scattering screen contains minute fibres of stainless steel which inhibit the passage, reflection, and return of a threat radar signal. The radar transparent version is made without these fibres.

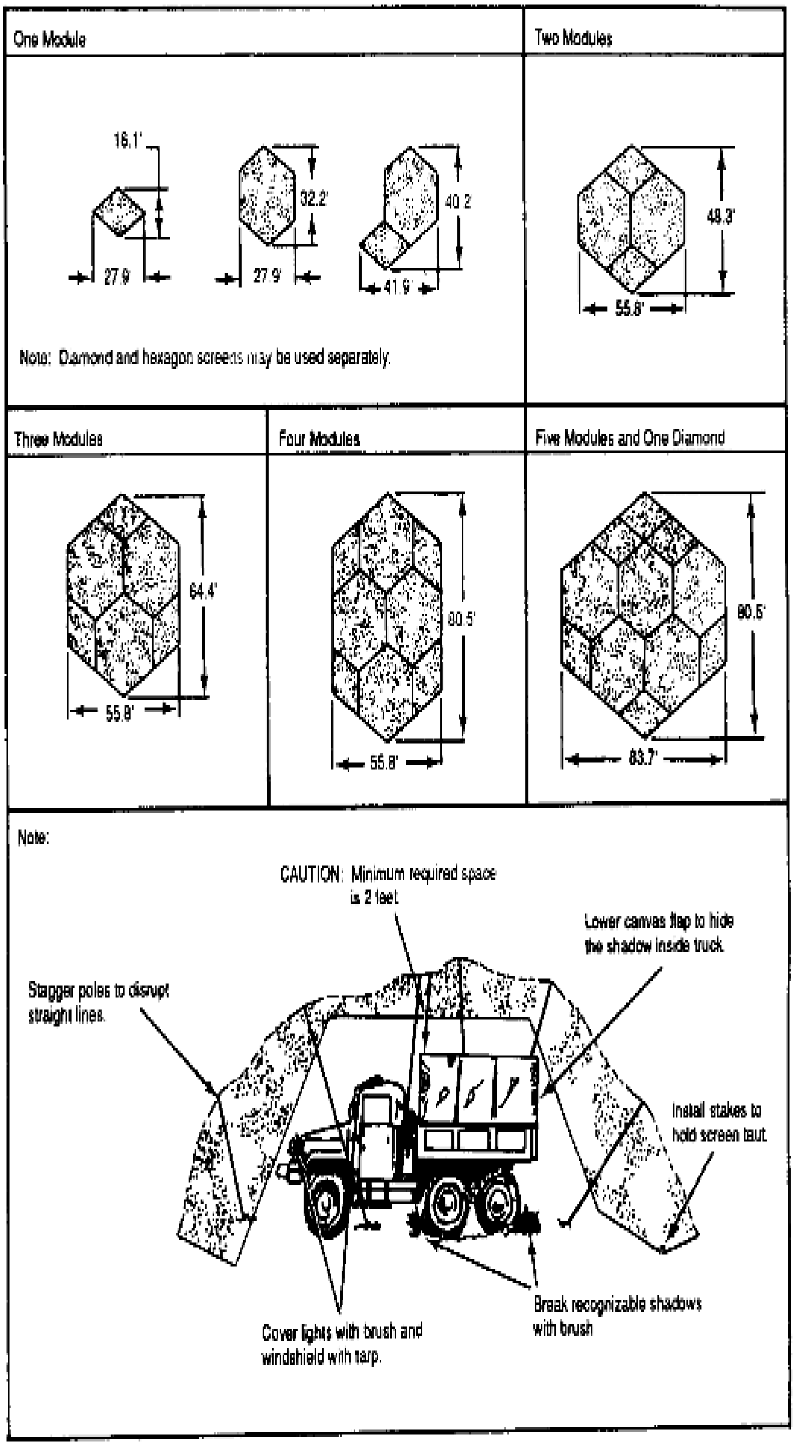


Figure B-1. LCSS Modular System

[64] www.fas.org

97. The desert version of the LCSS provides concealment against visual, near infrared, and radar target acquisition/surveillance sensor devices. A radar transparent version of the LCSS allows US units to camouflage radar without degrading operations. The desert camouflage net is a complete cover since it depends on ground surface imitation, both in colour and texture, for effect.

The LCSS conceals in four different ways:

(a) Casts patterned shadows that breakup the characteristic outlines of an object.

(b) Absorbs and scatters radar returns (except when radar-transparent LCSS is used).

(c) Dissipates infrared radiation.

(d) Simulates colour and shadow patterns that are commonly found in a particular region.

98. LCSSs can usually be set up in 20 to 25 minutes. When erecting the LCSS, keep the net structure as small as possible. Maintain the netting at a minimum of two feet from the camouflaged object's surface and avoid eye-catching steeples and shadows. Lines between support poles should be gently sloped so that the net blends into its background.

99. The net should extend completely to the ground to prevent creating unnatural shadows that are easily detected. This will ensure the LCSS effectively disrupts the object's shape and actually absorbs and scatters radar energy. The net should extend all the way around the object to ensure complete protection from enemy sensors.

100. The LCSS will rarely be used without supplemental camouflage. The LCSS does not make an object invisible. Other camouflage techniques are necessary to achieve effective concealment. Troops must cover or remove all of the object's reflective surfaces (such as mirrors, windshields, and lights) and ensure that they disrupt or disguise an object's shadow when camouflaging.

Three Colour Infrared Camouflage System[65]

101. A three-color camouflage system comprises layers of camouflage material having low, intermediate and high thermal emissivity in the infrared spectral range, and appearing black, green and brown in the visible spectral range.

(a) The first camouflaging layer (made of nickel oxide) having a low emissivity in the infrared spectral regions from 3 to 5 and 8 to 14 microns and a high emissivity in the visible spectral region from 400 to 700 millimicrons, thus appearing black to the human eye.

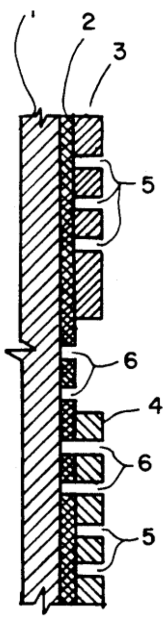
(b) The second camouflaging layer (fabric patches) having an intermediate emissivity in the infrared spectral regions and appearing green to the human eye in the visible spectral region, said second camouflaging layer bonded to the first layer in irregularly-shaped patches.

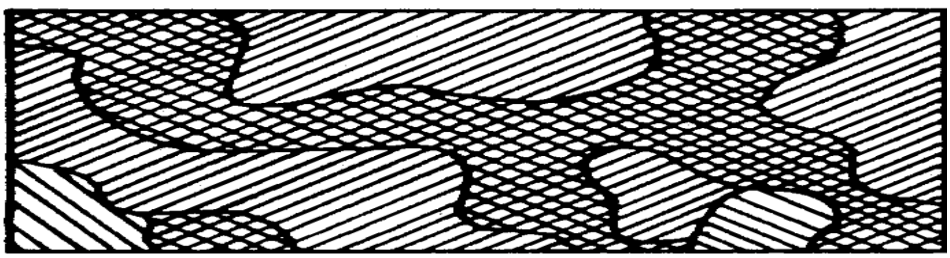
(c) The third camouflaging layer (fabric patches)having a high emissivity in the infrared spectral regions and appearing brown to the human eye in the visible spectral region, said third camouflaging layer being bonded to the first layer in irregularly-shaped patches.

102. The camouflage surface is structured in such manner that there is colour adaptation to the natural background in the visible spectral range, as well as adaptation to the natural background in thermal emissivity in the infrared spectral range so that targets cannot be recognized with infrared sensing devices.

103. Thermal emissivity in the infrared spectral range is controlled by superimposing layers of intermediate and high emissivity onto a basic low emissivity camouflage layer and providing perforations in these layers allowing the low-emissivity layer to be seen. High-emissivity areas are provided by perforations allowing the high-emissivity surface of the object being camouflaged to be seen. Alternatively, spots of high emissivity are superimposed on the three camouflage layers to provide areas of high emissivity. This camouflage system may also be used in the construction of decoys.

Figure 55





[65] US Patent and Trademark Office (Three Coloured IR camouflage System)

Low Emissive Camouflage Flakes[66]

104. A low emissive camouflage flake includes a metal layer having thermal reflective properties with at least one side of the metal layer coated with a coloured coating having thermal transparency properties.

105. The metal may be aluminium or any metal or alloy with similar properties. The coloured coating may consist of a lacquer, a thin plastic film, or it may consist of a thin metal/metal oxide layer, such as a sputtering deposit layer.

106. The metal layer gives the camouflage flake its low emission properties in the thermal radiation range while the coloured coating absorbs and or reflects radiation in certain parts of the visible radiation range, thereby giving the camouflage flakes a desired colour.

107. The low emissive camouflage flakes are camouflage active components which can be utilised in various applications in the field of camouflage to protect an object onto which they are applied from both visual and thermal detection. The low emissive camouflage flake may also comprise a stabilizing film, such as a polyester film, to simplify the manufacturing of the flakes.

108. By adding the low emissive camouflage flakes to a suitable binder, a skin camouflage (face paint) or a camouflage paint for protecting a user or an object, respectively, from visual and thermal detection is provided. The binders are substantially transparent to thermal radiation, particularly in the 3-5 and 8-14 micrometer wavelength regions, in order for the radiation to pass through the binder and be reflected by the low emissive camouflage flakes carried therein. Preferably, the binders are also transparent to visible light so that the perceived colours of the skin camouflage and the camouflage paint are given exclusively by the low emissive camouflage flakes.

Laser Pitting Technology[67]

109. The use of ultra-short laser bursts to make nearly imperceptible pockmarks in metal surfaces that can change the metal's colour by altering how the it absorbs and reflects light. This technology has the potential to change the colour of metal without paint.

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[66] US Patent and Trademark Office (Low Emissive Camouflage Flakes)

[67] mae.pennnet.com

Infrared Camouflage System[68]

110. The invention relates to a system for infrared (IR) camouflaging of land targets.

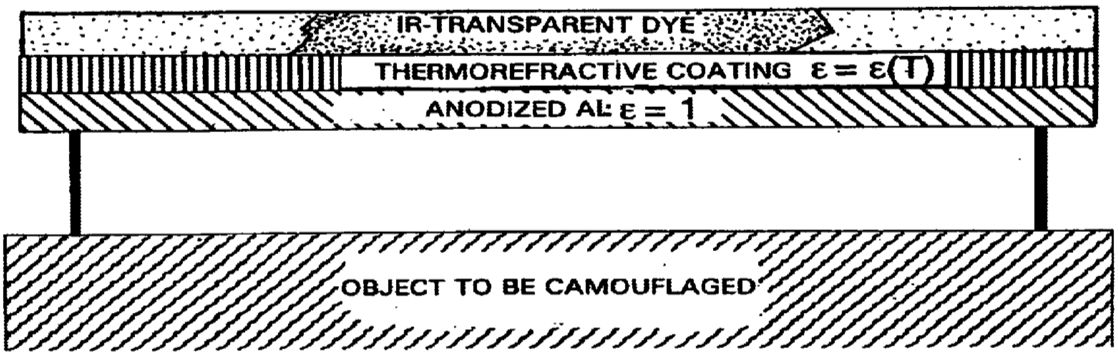
111. Known low emission camouflaging devices cannot easily be used for surfaces with a predominantly horizontal orientation, because these surfaces, when observable, always reflect predominantly celestial temperatures close to the zenith. The IR camouflaging mechanism of this system consists of the coordination of three effects:-

(a) At a low surface temperature (night, heavy clouds with low sun radiation), there is no need for any camouflage and the emissivity of the arrangement is high. The apparent surface temperature is well adapted to the ambient air temperatures and thus to that of the background.

(b) During solar heating, the emissivity decreases as the temperature rises, and therefore compensates the thermal radiation.

(c) Since typically there are few clouds (and therefore low celestial temperatures) when the sun is shining, the temperature-dependent emission behaviour of the thermo refractive layer can be pre-adjusted relatively well

Figure 56



and the temperature compensation can therefore take place very effectively.

112. However, the invention can be used not only for camouflaging surfaces which are essentially horizontal or inclined upward and is therefore suitable for aircraft hanger and other static installations.

113. The system comprises a thermo-refractive layer system or a thermo-refractive material, whose thermal emissivity has a negative temperature coefficient.

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[68] US Patent and Trademark Office (Infrared Camouflage Systems)

Flexible Camouflage System[69]

114. The system utilises special flexible tiles which have specific multi-spectral camouflage properties to provide concealment from Visual, Near IR, Thermal and radar. The camouflage is effective in all environments, both cold and hot climates, dry or wet conditions. Tiles are specifically designed for each section of the vehicle, and can be adapted to every size and shape of vehicle.

Mobile Camouflage System[70]

115. MCS is designed to protect armoured vehicles during movement and in combat. The system utilizes different materials, for camouflage in the visual/near IR, thermal, and radar wavebands. Further enhancement of the system includes the application of heat transfer reduction materials, to conceal the heating of the vehicle by solar radiation.

116. The general approach of the MCS is to hide glossy or flat surfaces into non-glossy 3 dimensional surface structures, with colour and near infrared values similar to the environmental condition of the region. Significantly recognizable parts of the vehicle, such as turret shapes and gun will also be concealed with contour disrupters. An ideal camouflage will also obstruct laser reflections to affect the enemy's range measurement accuracy.

117. The thermal and radar camouflage contributes to the elimination thermal or radar locking of heat seeking missiles and obstruct and disrupt target detection and tracking by ground or aerial weapons. Radar camouflage will also eliminate the detection by synthetic aperture radar.

[69] www.defense-update.com
[70] Abid.

Camouflage Nets

118. There are far too many permutations and combinations to list out. The purpose of the camouflage net is to prevent microwaves which impinge upon any object from being reflected by that object. It should also prevent identification by sensors operating in the infrared and thermal imaging range. This means that it should not be possible to recognize or identify the objects to be camouflaged by active video receivers in the 0.7-1.8 µm range or by passive video receivers in the 3-5 µm and 8-14 µm range. Various camouflage nets are already known for this purpose.

119. In the atmospheric windows around 26-40 and 92-96 GHz natural objects, such as a grass and plants, behave like black body radiators with an emission level of almost one, whereas military objects, such as armoured vehicles, lorries, etc. made of metal have an emission level of approximately zero and therefore a remission level of approximately one. Therefore the latter are ideal reflectors, with one part of the beam being directed, while one part provides a diffused reflection.

120. This means that with radiometric measurements from above the object to be camouflaged, e.g. a military object, reflects thermal radiation into the sky with a temperature of 30K at 35 GHz and 100K at 94 GHz, whereas the environment radiates as a black body radiator with ambient temperature.

121. The military object therefore behaves like a very cold target in a warm environment, with the temperature contrast being between 240K and 280K. In this way it can be detected as a cold body with a microwave radiometer. When the sky is overcast and it is still high enough for armoured vehicles to be located with a passive microwave seeker head for the final phase guidance of shells and missiles.

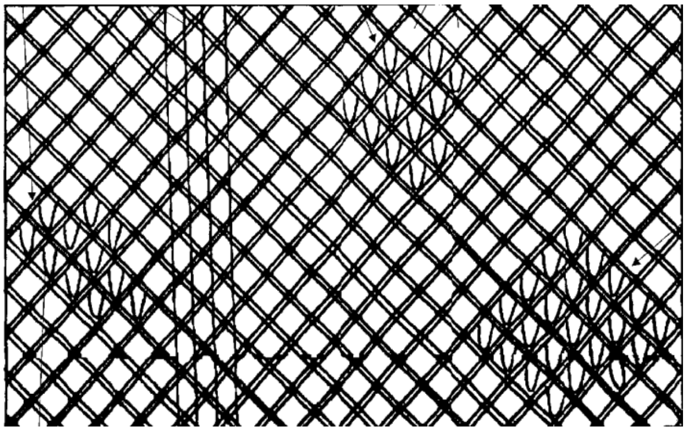
122. Further, there is a problem, when they are used in desert regions, camouflage nets, which are based on the principle of convection, are too cold by day and too warm at night when used in the desert. The sand, rocks and vegetation heat up to an extreme extent in the desert throughout the day due to the sun. The region which is covered by the camouflage nets is shaded by the camouflage nets and thus becomes colder since the covered ground surface cannot heat up to the same extent. A signature which differs from the surroundings therefore appears in the thermal infrared range.

123. Therefore nets have been made to be multispectrally effective flame-retardant camouflage net, which gives protection in the visible and near infrared range, displays good damping values over a wide spectrum of the microwave range and is a low emitter in the thermal imaging range and possess good mechanical strength and flexibility characteristics over the widest possible temperature range.

Figure 57

124. Camouflage nets can attenuate radar signals from 5 to 100 GHz and especially from 8 to 40GHz. The level of attenuation in each band varies (from 10Db up to 35Db) while RCS reduction is 99%. On top of that all fabrics are treated /painted with the anti-thermal coatings and literally any camouflage pattern can be designed. The modern Fabrics do not need to be kept away from any hot surface; they do not get hot when placed directly on top of a warm surface. They weigh as low as 200 gm/m^2 and can be engineered to meet end-user specifications i.e. weight, design, pattern, performance.

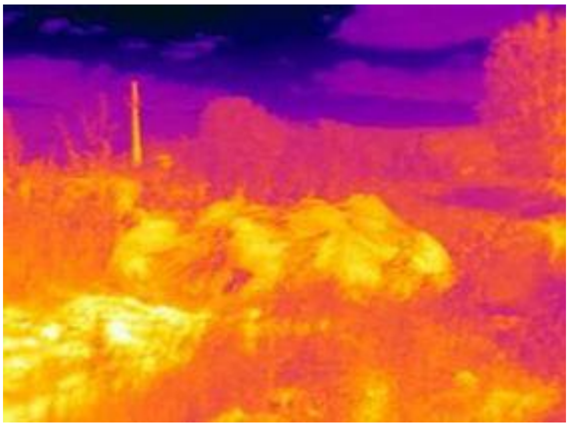
Figure 58



125. For the deserts condensed regions of the knitted fabric are produced as Jacquard patterns, which have particularly good limitation of the airflow and can have different shapes and sizes, depending on requirements or on the particular desert area. The frequency and arrangement of the Jacquard patterns may also be varied correspondingly.

Figure 60

Figure 59



CamoTek Multi Spectral Camouflage Net[71]

126. The CamoTek Multi-Spectral camouflage net is an advanced system designed and targeted to increase the survivability of armoured vehicles, fighting soldiers and their equipment. The Multi-Spectral net is effective against all of the modern battlefield threats, and provides protection against sensors in the Visual, Near IR, Thermal and Radar spectrums as under:-

(a) Visual Threat. Visible light wave lengths of 380 to 700 Nanometres (Nm).

(b) Near Infrared Threat. Invisible radiation in wavelength of 700 to 2500 Nm.

Figure 61

Uncamouflaged Truck | Visually Camouflaged | NIR Image

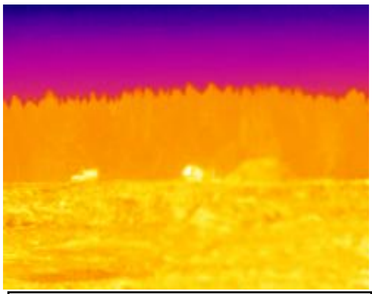
(c) Thermal Threat. The thermal band is active in the 3 to 5 micron and 8 to12 micron spectrum. CamoTek uses a unique technology based on 3 parameters:-

(i) Transmission (passage of energy). Screen construction.

(ii) Reflectivity. Adaptive and varied reflection values.

(iii) Emissiveness. Adaptive and varied emission values.

Figure 62



8-12 microns camouflaged tank next to 2 exposed reference jeeps

(d) Radars. CamoTek's approach for overcoming the radar threat is by scattering the radar waves. The net scatters incoming signals, reflecting them in many different angular directions and reducing the reflected image received by the enemy radar. By utilising the radar specification net and its unique structure, which is manufactured from several special developed raw materials, a target shield is provided which scatters the signal, confusing the enemy sensors and significantly reducing the target reflection.

[71] www.**m2dltd.com**

STEALTH

Background

127. Stealth technology (low observable technology) is a sub-discipline of military tactics and passive electronic countermeasures, to make objects less visible (ideally invisible) to radar, infrared, sonar and other detection methods. The concept of stealth is to operate or hide without giving enemy forces any indications as to the presence of friendly forces. This concept was first explored through camouflage by blending into the background visual clutter. In simple terms, stealth technology allows a system to be partially invisible to Radar or any other means of detection (other than visual). It must be understood that it does not make you completely 'invisible'. Stealth technology primarily deals with signature management (discussed earlier) and an amalgamation of the technologies to achieve this to render one's self 'Less Detectable'. It is not so much a technology as a concept that incorporates a broad series of technologies and design features.

Figure 63

128. History. In the nineteenth century, Scottish physicist James Clerk Maxwell developed a series of mathematical formulas to predict how electromagnetic radiation would scatter when reflected from a specific geometric shape. His equations were later refined by the German scientist, Arnold Johannes Sommerfield. But for a long time, even after aircraft designers attempted to reduce radar signatures for aircraft like the U-2 and A-12 OXCART in the late 1950s, the biggest obstacle to success was the lack of theoretical models of how radar reflected off a surface. In the 1960s, Russian scientist Pyotr Ufimtsev began developing equations for predicting the reflection of electromagnetic waves from simple two-dimensional shapes. His work was regularly collected and translated into English and provided to U.S. scientists. By the early 1970s, a few U.S. scientists, mathematicians, and aircraft designers began to realize that it was possible to use these theories to design aircraft with substantially reduced radar signatures. Lockheed Aircraft, working under a contract to the Defence Advanced Research Projects Agency, soon began development of the F-117 stealth fighter.

129. Limitations.[72] Stealth, like everything else is not impervious to its limitations. The most prominent being the constant development in surveillance technology. Coupled to this is the radar which can still detect very small radar signatures, stealth aircraft are also operated in a careful manner and assisted by other aircraft. For instance, they try to avoid certain radars and operate in conjunction with aircraft designed to jam enemy radar.

(a) Low Frequency Radar. Shaping does not offer stealth advantages against low-frequency radar. If the radar wavelength is roughly twice the size of the target, a half-wave resonance effect can still generate a significant return. However, low-frequency radar is limited by lack of available frequencies which are heavily used by other systems, lack of accuracy given the long wavelength, and by the radar's size, making it difficult to transport. A long-wave radar may detect a target and roughly locate it, but not identify it, and the location information lacks sufficient weapon targeting accuracy. Noise poses another problem, but that can be efficiently addressed using modern computer technology; Chinese "Nantsin" radar and many older Soviet-made long-range radars were modified this way. It has been said that "there's nothing invisible in the radar frequency range below 2 GHz".

(b) Multiple Transmitters. Much of the stealth comes from reflecting the transmissions in a different direction other than a direct return. Therefore detection can be better achieved if the sources are spaced from the receivers, known as bistatic radar, and proposals exist to use reflections from sources such as civilian radio transmitters, including cellular telephone radio towers.

[72] wikipedia

(c) Acoustics. Acoustic stealth plays a primary role in submarine stealth as well as for ground vehicles. Submarines have extensive usage of rubber mountings to isolate and avoid mechanical noises that could reveal locations to underwater passive sonar arrays.

(d) Visibility. The simplest stealth technology is simply camouflage; the use of paint or other materials to colour and break up the lines of the vehicle or person. Most stealth aircraft use matte paint and dark colours, and operate only at night. Lately, interest on daylight Stealth (especially by the USAF) has emphasized the use of gray paint in disruptive schemes, and it is assumed that Yehudi[73] lights could be used in the future to mask shadows in the airframe (in daylight, against the clear background of the sky, dark tones are easier to detect than light ones) or as a sort of active camouflage.

(e) Infrared. An exhaust plume contributes a significant infrared signature. One means of reducing the IR signature is to have a non-circular tail pipe (a slit shape) in order to minimize the exhaust cross-sectional volume and maximize the mixing of the hot exhaust with cool ambient air. Often, cool air is deliberately injected into the exhaust flow to boost this process. Sometimes, the jet exhaust is vented above the wing surface in order to shield it from observers below, as in the B-2 Spirit, and the unstealthy A-10 Thunderbolt II. To achieve infrared stealth, the exhaust gas is cooled to the temperatures where the brightest wavelengths it radiates on are absorbed by atmospheric carbon dioxide and water vapour, dramatically reducing the infrared visibility of the exhaust plume. Another way to reduce the exhaust temperature is to circulate coolant fluids such as fuel inside the exhaust pipe, where the fuel tanks serve as heat sinks cooled by the flow of air along the wings.

(f) Reducing Radio Frequency (RF) Emissions. In addition to reducing infrared and acoustic emissions, a stealth vehicle must avoid radiating any other detectable energy, such as from onboard radars, communications systems, or RF leakage from electronics enclosures. The F-117 uses passive infrared and low light level television sensor systems to aim its weapons and the F-22 Raptor has an advanced Low Probability of Intercept LPI radar which can illuminate enemy aircraft without triggering a radar warning receiver response.

130. Stealth is at the cutting edge of many technologies and these limitations by no means take away their efficacy in the modern battlefield. Pioneered by the Air force, the Navy and Army too are now making inroads into this concept.

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[73] Yehudi lights are lamps placed on the underside of an aircraft to raise luminance, to disguise the aircraft against the background sky.

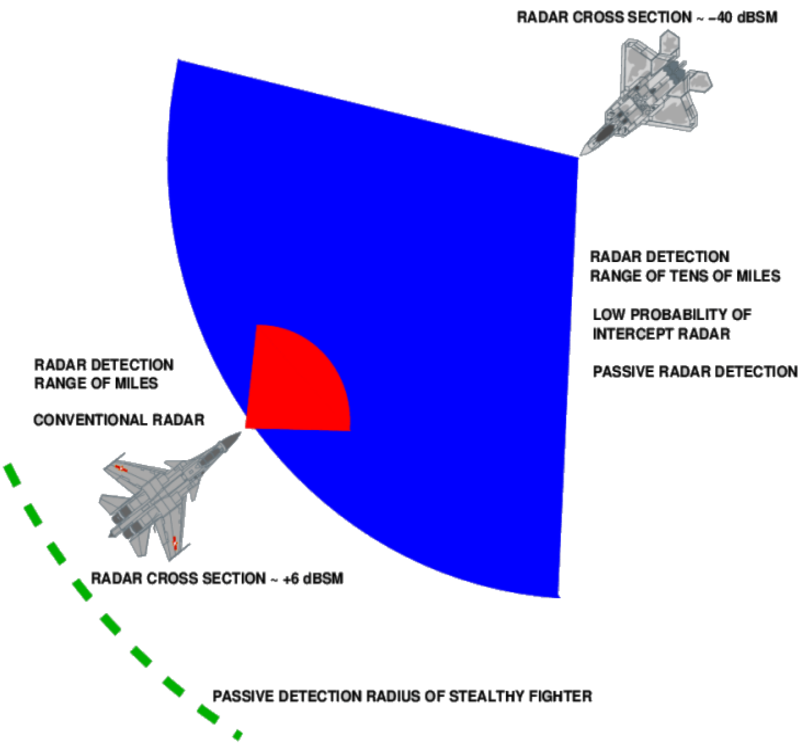
Application of Stealth Technology to Aircrafts and Helicopters

131. Necessity. The all weather radar guided Beyond Visual Range (BVR) missile is now a mainstay of both air defence and air superiority combat operations. It spawned large and heavy fighters with powerful air intercept radars, and together with the Surface-Air Missile (SAM) provided the impetus for the development of stealth. Radar guided BVR missiles have also evolved dramatically, and now are becoming extremely difficult to defeat by manoeuvre or jamming. Moreover we are beginning to see the first air-air anti-radiation seekers, which will home on an opposing fighter's air intercept radar, and we are also seeing air breathing BVR weapon proposals. An air breathing BVR missile will have double or triple the range of a pure rocket missile of similar size, as it need not carry the oxidising agent in its propellant; it sucks it in as it flies. We can also expect to see the first generation of hybrid seekers, combining anti-radiation and or radar homing with heat seeking guidance. Such missile seekers are virtually impossible to jam as they will continuously compare the quality of sensor outputs, and select that which is providing the best quality signal. If one is jammed, it switches to the other, and vice-versa, frustrating virtually any conventional jamming strategy.

132. The technology however does exist to deal with this problem, and has existed for almost two decades. It is stealth.

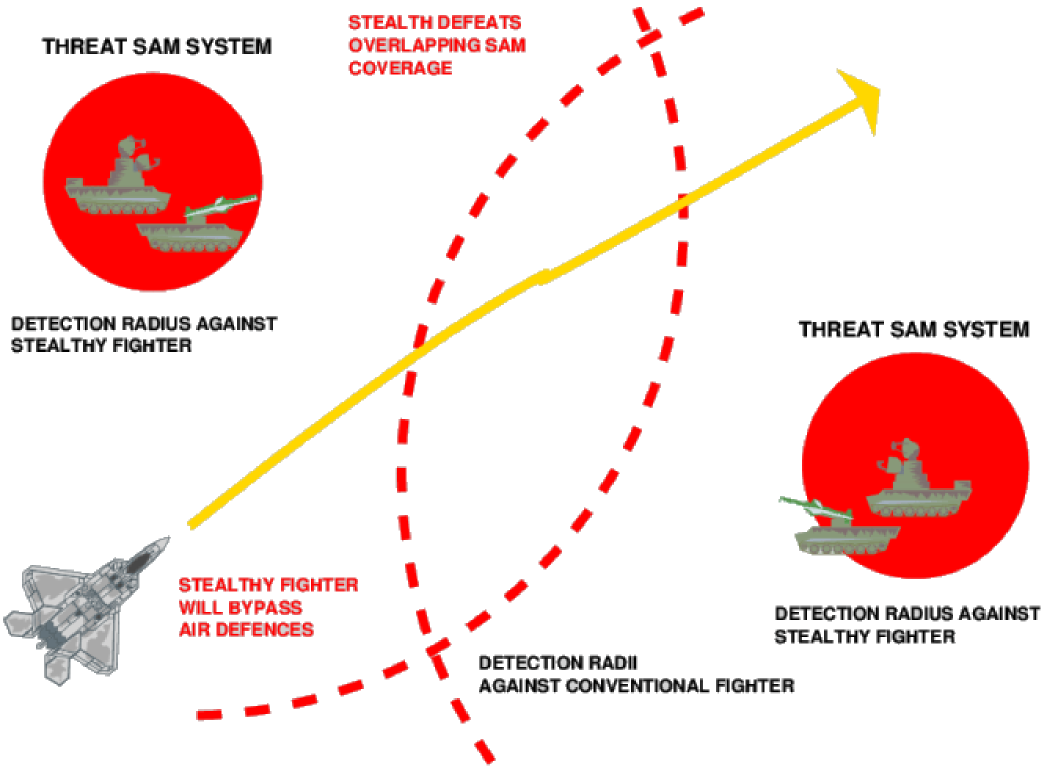
133. Stealth means suppressing the radar cross section and infrared signatures of an aircraft to the point where it cannot be detected until it is several miles away or even closer if we factor in lower performance in air intercept radars and missile seekers, compared to large ground based equipment. As a result, a stealthy aircraft can approach to weapons launch range without its opponent knowing it is there, launch its weapons and then vanish again.

Figure 64



CONVENTIONAL AIR SUPERIORITY FIGHTER VS STEALTHY AIR SUPERIORITY FIGHTER

Figure 65



STEALTHY STRIKE FIGHTER VS SAM SYSTEMS

Note: Some stealth aircraft will be discussed in the succeeding pages. These aircraft have been chosen for discussion on

‘Stealth and its Impact of Aeroplanes’

as they all employ certain technologies worth enumerating. Further they are all meant for varying roles and therefore display the diversity of application of this concept.

Aircraft like the ‘Bird of Prey’ or the ‘Have Blue’ etc have not been covered as there is apparently no research going on them. Successful technologies have been covered in the aircrafts discussed below and hence no duplication was felt necessary.

Details about the aircraft like the Sukhoi S 37/47 etc are not readily available and generic information as to the technology used in them is not in variance to the aircrafts covered in stealth aspects. Certain avionic aspects having an indirect bearing may be different but are not part of the scope here. The possibility of this aircraft using Plasma Technology is however covered separately in this section.

134. F-117A 'Night Hawk'.[74] Development of the stealth aircraft began in the early 1970s, with the Experimental Stealth Tactical (XST), code-named "Have Blue." This project resulted in the Lockheed F-117A, with 20 of these aircraft ordered from Lockheed by the Air Force in 1981, and a total of 59 aircraft were produced. The F-117A first flew in 1983. Although the F-117A exhibits breakthrough low-observable characteristics, it was not built from scratch. Designers modified F-16 flight controls and F-18 engines. Lockheed officials say that using and improving on existing technology, rather than re-inventing the wheel, allowed them to make the F-117A at half the cost and in half the time of equivalent aircraft. The F-177A first saw combat in the American intervention in Panama in December 1989, when two of the aircraft were used to attack an airfield, but this mission was marred by pilot error which caused one of the aircraft's bombs to land far from the intended target. The F-117A performed well in Desert Storm, which may be the primary reason that the aircraft's production line, once slated for closure, has recently been revived.

Figure 66

Figure 67

- Crew: 1
- Length: 69 ft 9 in (20.08 m)
- Wingspan: 43 ft 4 in (13.20 m)
- Height: 12 ft 9.5 in (3.78 m)
- Wing area: 780 ft² (73 m²)

Surface and edge profiles optimised to reflect hostile radar into narrow beam signals.

All doors and opening panels on aircraft have saw toothed and trailing edges to reflect radar.

Mainly constructed from aluminium with titanium for areas of exhaust systems.

Outer surface covered with radar absorbent material.

RCS estimated at 10 – 100 cm^2

Rectangular air intakes on both sides of fuselage are covered by gratings coated with radar absorbent material.

Wide and flat structure of engine exhaust area reduces IR and radar detectibility.

Two large tail fins slant slightly outwards to obstruct IR and radar returns from exhaust area.

Avoids sharp banks to evade enemy radar.

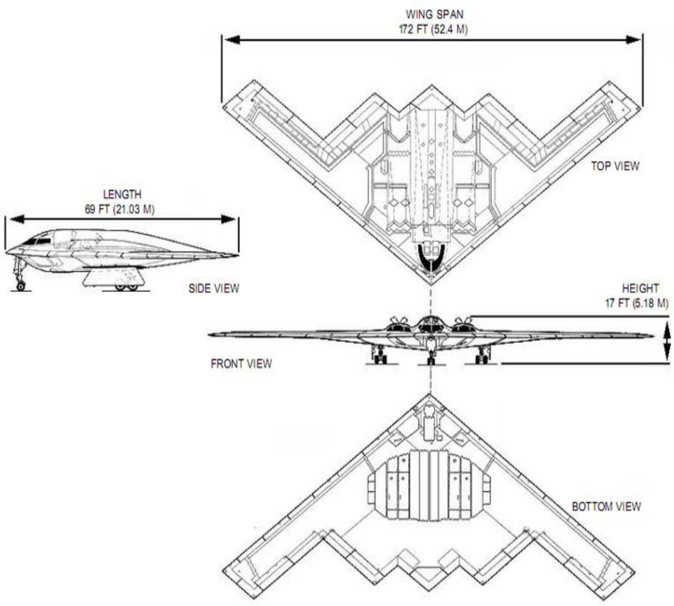
Fibre Radio Optical ARCS (Active Radar Cancellation System)

[74] Wikipedia, howstuffworks.com

135. Advanced Technology Bomber (ATB) B-2.[75] The Stealth Bomber project was first announced by the Carter Administration in the heat of the 1980 Presidential campaign, in response to Republican criticism of the decision to cancel the B-1A bomber. Since it's unveiling in November 1988, the B-2 has been the focus of mounting criticism of the inexorably growing cost of the project, the regularity with which its schedule has been delayed, and doubts about mission requirements. The B-2 will be the most expensive aircraft ever procured, and by some estimates each bomber will literally cost its weight in gold. Two missions for the B-2 emerged from the veil of secrecy. Some advocates argued that the B-2 is needed to offset improvements in Russian air defences, and that the exertions the Russian would make to augment their air defences to counter the B-2 will inhibit their efforts in strategic offensive and conventional forces. Others argue that the B-2 is needed in order to attack Russian mobile missiles such as the SS-24 and SS-25.

Figure 69

Figure 68



Flat narrow shape.

Black colour radar absorbent surface made of composite highly reflective metal components.

Air flow through an S shaped duct.

Aerodynamic design to reduce noise.

Engine inside to muffle noise, and reduce IR signature.

Retractable and covered landing gear, bombs etc.

Large flat areas on top and bottom act like tilted mirrors.

Curved, no sharp angled edges.

Designed to contain its own EM signals inside.

Efficient sweep angle.

- **Crew:** 2
- **Length:** 69 ft (21.0 m)
- **Wingspan:** 172 ft (52.4 m)
- **Height:** 17 ft (5.18 m)
- **Wing area:** 5,140 ft² (478 >m²)

[75] Wikipedia, howstuffworks.com

Figure 70

136. F-22 Raptor. [76] The Lockheed Martin/Boeing F-22 Raptor is a fifth-generation fighter aircraft that uses stealth technology. It was designed primarily as an air superiority fighter, but has additional capabilities that include ground attack, electronic warfare, and signals intelligence roles. Lockheed Martin Aeronautics is the prime contractor and is responsible for the majority of the airframe, weapon systems and final assembly of the F-22. Program partner Boeing Integra ted Defence Systems provides the wings, aft fuselage, avionics integration, and all of the pilot and maintenance training systems. The aircraft was variously designated F-22 and F/A-22 during the years prior to formally entering US Air Force service in December 2005 as the F-22A.

Radar absorbent material.

S-shaped intake ducts that shield the compressor fan from reflecting radar waves,

Attention to detail such as hinges and pilot helmets that could provide a radar return.

Designed to disguise its infrared emissions to make it harder to detect by infrared homing missiles.

Made the aircraft less visible to the naked eye.

Controlled radio and noise emissions.

An under bay carrier made for hiding heat from missile threats, like surface-to-air missiles.

Less maintenance-intensive RAM and coatings than previous stealth designs like the F-117.

Unlike the B-2, which requires climate-controlled hangars, the F-22 can undergo repairs on the flight line or in a normal hangar.

The F-22 has a warning system (called "Signature Assessment System" or "SAS") which presents warning indicators when routine wear-and-tear have degraded the aircraft's radar signature to the point of requiring more substantial repairs.

The exact radar cross section of the F-22 remains classified. In early 2009 Lockheed Martin released information on the F-22, showing it to have a radar cross section from certain critical angles of -40 dBsm — the equivalent radar reflection of a "steel marble".

However, the stealth features of the F-22 require additional maintenance work that decreases their mission capability rate to approximately 62-70%.[84]

While its radar cross-section is almost nonexistent, this is merely a static measurement of the aircraft's frontal or side area and is valid only for a radar source in a stationary location relative to the aircraft. As soon as the F-22 manoeuvres, it exposes a different set of angles and a greater surface area to any radar, increasing its visibility.

Horizontal flat surfaces (such as the sides of the fuselage and other more vertical surfaces) were painted more darkly, and areas that are usually not quite as bright (such as the sides of the fuselage and other more vertical surfaces) were painted a lighter shade of gray. This reduced the overall contrast of the aircraft, making the whole shape appear to be one relatively even shade of gray.

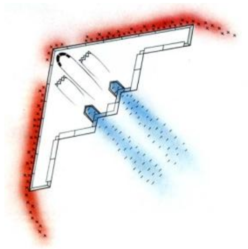
[76] Wikipedia, howstuffworks.com

137. The airframes of the aircrafts discussed above are designed to minimize their RCS and avoid all possible elements of the structure, which could reflect electromagnetic radiation. In order to minimize reflected RAM are also applied to the surface of the structure. The main drawback of the Stealth technology is its negative effects on the flight and agility characteristics of the stealth aircrafts. Russian scientists approach the issue from the other direction. They proposed to create a plasma formation around protected object, which prevents radars from seeing it. Thus, aerodynamic characteristics of the plane itself do not suffer.

138. Plasma Stealth.[77] If an object is surrounded by a cloud of plasma, several phenomena are observed when the cloud interacts with electromagnetic waves radiated by enemy radar.

(a) First, absorption of electromagnetic energy occurs in the cloud; since during plasma penetration it interacts with plasma charged particles, pass onto them a portion of its energy, and fades.

Figure 71



(b) Second, due to specific physical processes, electromagnetic wave tends to pass around plasma cloud. Both of these phenomena results in dramatic decrease of the reflected signal.

(c) Certain Reservations.[78]

(i) EM waves have a tendency to bend around the plasma field thus passing around the aircraft. Aerospace radar specialists feel that this effect is at best minimal in decreasing Radar Cross Section (RCS).

(ii) Plasma can disturb electromagnetic waves to the point of transforming them to differing frequencies scattered all across the RF spectrum, rendering the electromagnetic waves that encounter the plasma virtually useless.

(iii) An electromagnetic field is generated - the downside however, is that such a field would be detectable by electronic sensors.

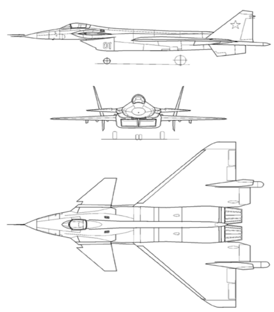
MiG 39 (1.42/1.44) (Plasma Stealth).

Wingspan: >15

Length overall: >20

Maximum speed (km/h): M=2,6`

Figure 72



[77] www.military-heat.com
[78] www.abovetopsecret.com

139. <u>Stealth Helicopters.</u>[79] The RAH-66 Comanche is recognised worldwide as the closest resemblance to a stealth helicopter. Trials are on in major countries for No Tail Rotor (NOTOR), Twin rotor and other such application to reduce signatures. The Comanche however is the closest in the family to be ratified. The stealth features it incorporates are mentioned below.

RCS has been minimised, primarily by the precisely shaped fuselage and internal weapons configuration.

Tail rotor merged into tail section – reduces the acoustic signatures.

Fully retractable missile armament system to maintain its low stealth profile.

Composite material fuselage with RAMs.

Figure 73

The Comanche RAH-66 reconnaissance and attack helicopter was being developed by Boeing and Sikorsky for the US Army. The first flight of the Comanche took place on 4 January 1996. The programme entered engineering and manufacturing development in June 2000. Critical design review of the overall weapon system was completed in June 2003 and was to be followed by low rate initial production of 78 helicopters in three batches in 2007. In February 2004, the US Army announced that it planned to cancel further research, development and planned purchases of the RAH-66 Comanche stealth helicopter. It believed that the helicopter would not meet the requirements of changing operational environments.

[79] armytechnology.com
wikipedia.com

Application of Stealth Technology to Ships and Submarines

140. Signature management for naval vessels has already been discussed. Naval vessels are peculiar in their requirements for stealth.

141. In designing a ship with reduced radar signature, the main concerns are radar beams originating near or slightly above the horizon (as seen from the ship) coming from distant patrol aircraft, other ships or sea-skimming anti-ship missiles with active radar seekers.

142. Therefore, the shape of the ship avoids vertical surfaces, which would perfectly reflect any such beams directly back to the emitter.

143. Retro-reflective right angles are eliminated to avoid causing the *cat's eye*[80] effect. A stealthy ship shape can be achieved by constructing the hull and superstructure with a series of slightly protruding and retruding surfaces.

Figure 74

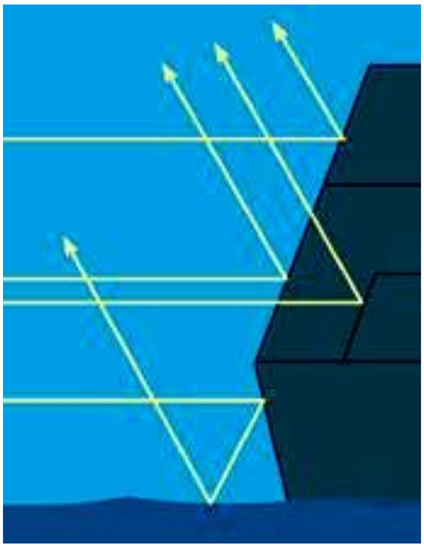


Figure 75

"FULL-STEALTH"	CONCEPT	"CONVENTIONAL"
Composite	Structure	Steel/aluminium
Diesels/gas turbines w underwater/stern exhausts	Machinery	Diesels/gas turbines w funnel/stack
Waterjets	Propulsion	Propellers & rudders
	SUSCEPTIBILITY	
	Radar (%)	
	Infrared (%)	
	Hydro-acoustic (%)	
	Magnetic (%)	
	Electric (%)	
	Visual (%)	
	VULNERABILITY	
	Fire (%)	
	Ballistic (%)	
	Blast (%)	
	UNDEX (%)	

[80] In radar interpretation, an object that has multiple reflections from smooth surfaces produces a radar return of greater magnitude than might be expected from the physical size of the object.

Chart 1

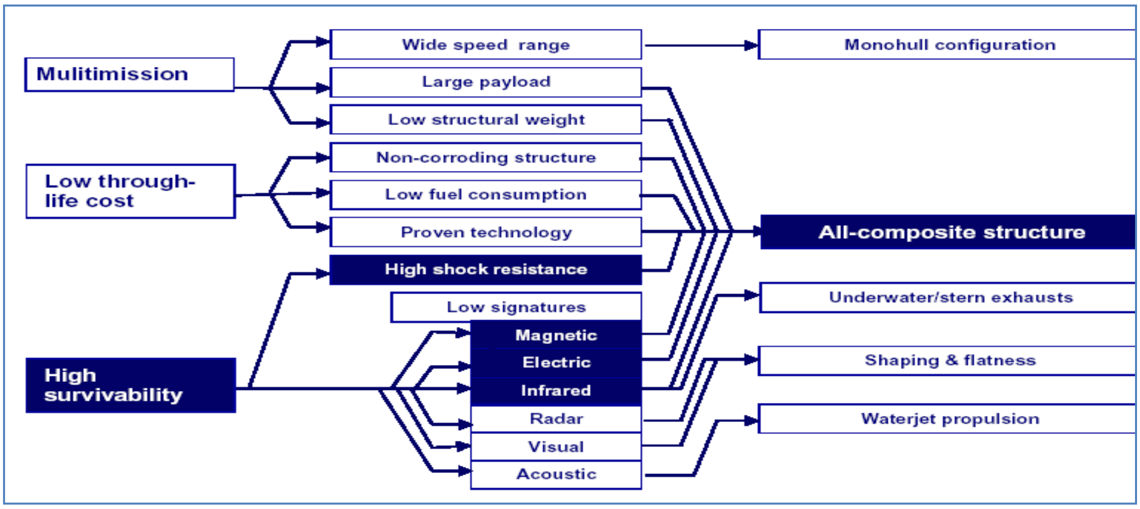


Figure 77

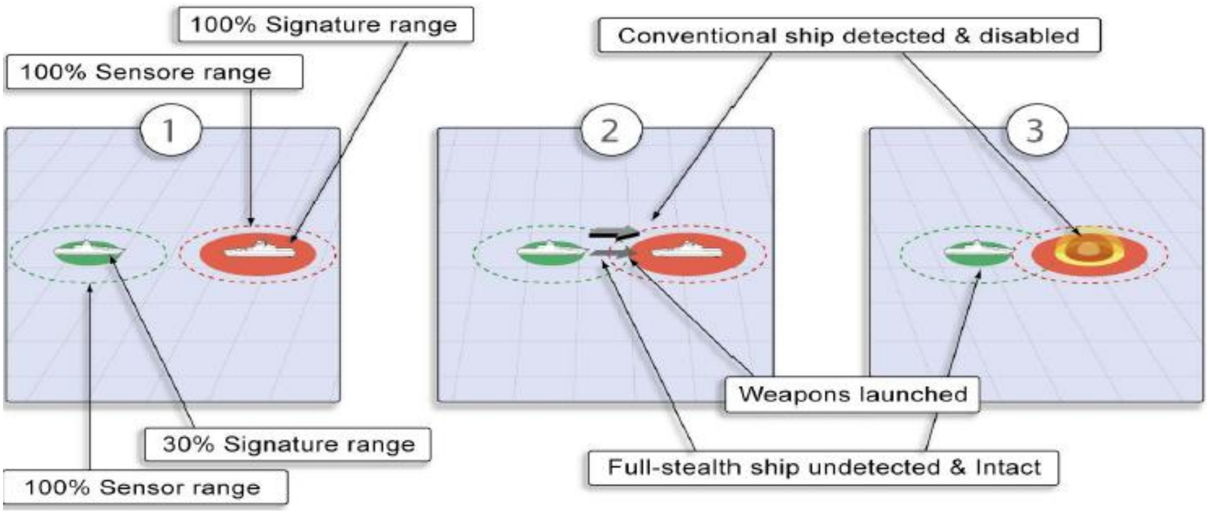
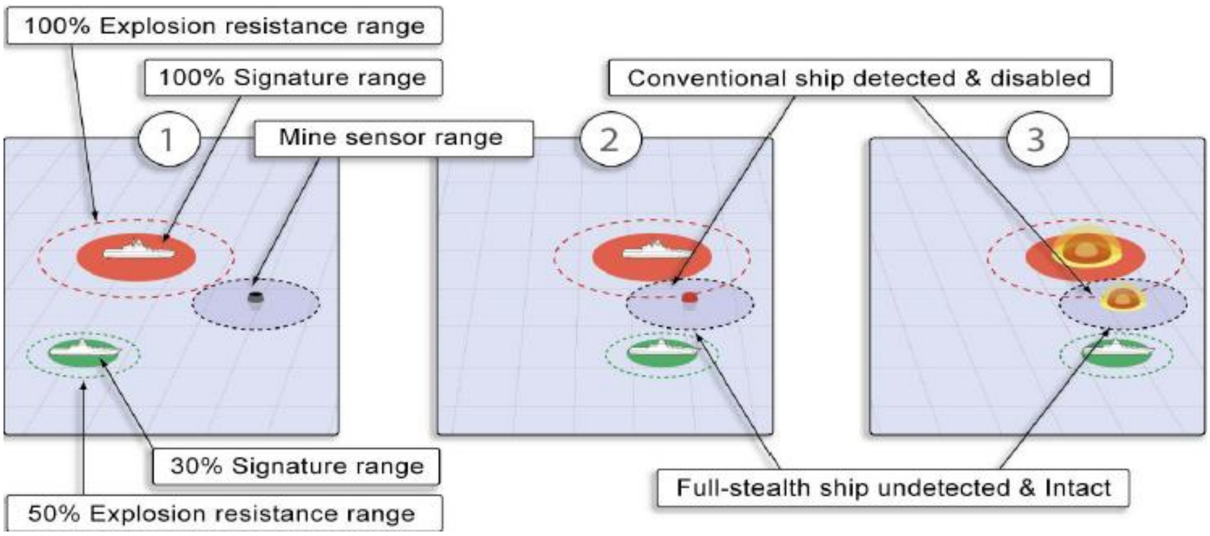


Figure 76

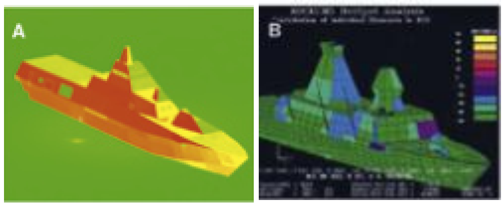


144. Visby Corvettes.[81] Visby class corvettes were the first stealth ships to be made.

Figure 78

(a) Visby's hard-edge hull and super-structure limit radar reflection to four main directions and a single angle of elevation, by critical arrangement of their flat surfaces.

Figure 79



(b) Low infrared signature, with neither hot nor cold spots that stand out against a temperature-neutral background, because the exhaust of her engines and generators is triple-cooled and exits aft, near the water's surface. Below decks ventilation emissions are concealed.

(c) Visby's hull material is thermo-insulating and exterior paint is selected for optimum heat insulation as well as camouflage.

(d) The low acoustic signature is achieved first by:-

(i) Water jets, which generate much less propulsion noise than propellers.

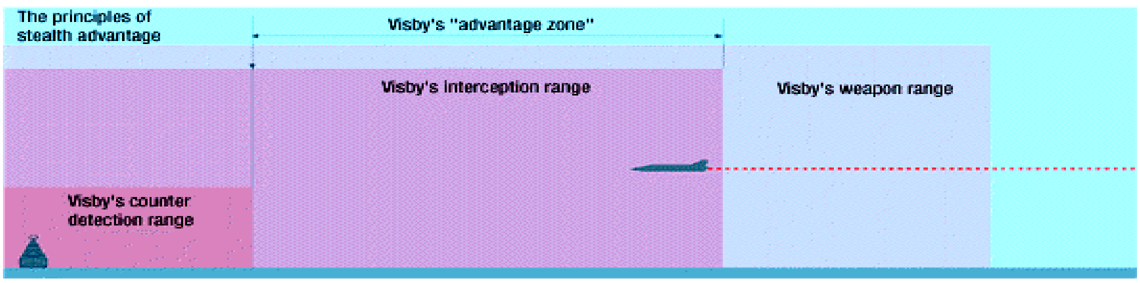
(ii) Propulsion diesels and generator sets are double-elastically mounted to minimize transmission of noise and vibration into the hull, and are covered by sound-absorbing hoods.

(iii) All other noise-generating equipment such as pumps and fans are mounted to damp out their natural vibration.

(e) The hull material is non-magnetic, and standard equipment components, where feasible, are selected for their non-magnetic characteristics.

(f) Carbon fibre shields against a wide range of electromagnetic signals.

Figure 80



81 Visby e-brochure

145. Other measures taken in the Visby and other ships too are:

(a) Concealed installation of weapons, sensors, sonar, cranes, boats etc.

(b) All external doors and hatches of “smart” design, with conductive coating.

(c) Stealth adaptation and platform integration of all above-deck equipment.

(d) Use of flush-mounted, cavity-backed, miniature and retractable antennas.

(e) Use of frequency selective surfaces (FSS) for covering some antennas.

(f) Limited use of radar absorbent material (RAM).

(g) Special attention is given to the design of external details, e.g. air intakes/outlets, windows etc.

Figure 81

French frigate Surcouf of the La Fayette class

Figure 82

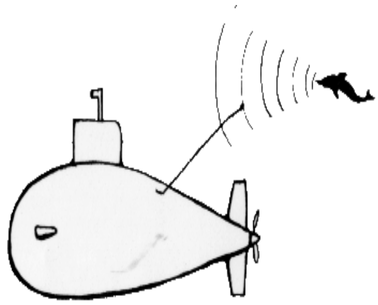
The U.S. Navy's *Sea Shadow* (IX-529)

Figure 83

INS *Shivalik* – under construction. Apart from evading radar and acoustic sensors, the ship is engineered to give-off minimal infra-red emissions.

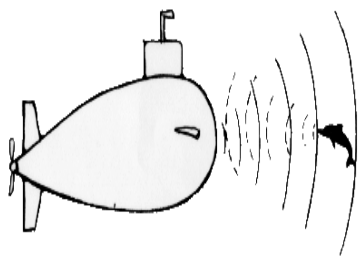
146. Submarine Stealth. [82] The development of RADAR (Radio, Detection and Ranging) during World War II allowed surface ships to talk with submarines and warn them of impending danger. Radio communication was established with a retractable antenna from the sub that rose above the surface. In order for this to work, the submarine had to come close to the surface. Another danger was that the radio transmissions could be detected and tracked, threatening to reveal the sub's location. It wasn't until the introduction of SONAR (Sound Navigation and Ranging) that submarines were able to capitalize on their stealth. In order to go undetected, submarines needed something that concealed them from other boats or ships. SONAR offered submarines stealth. SONAR is a system that uses sound waves travelling through water to search for objects or geographic obstacles. There are two types of SONAR, passive and active.

Figure 84



(a) Passive Sonar. It picks up sounds using electronic listening equipment. A target can be detected by the noise it makes from its machinery, the propeller, or the sound of the water passing around the vessel as it travels.

Figure 85



(b) Active Sonar. It produces and emits a burst of sound or a "ping." This is reflected back when it hits an object and is registered as a "blip "on a screen. Active Sonar sends and receives sound transmissions. There is a danger that enemy Sonar will detect the ping.

147. Sonar is very important to submarines because it lets them see what is around them, without coming close to the surface. Submariners must listen carefully, because Sonar can pick up other sounds made by their own sub or sea creatures. When a sub is listening for a target, it also must be very quiet. Submariners even wear tennis shoes when underway to silence their footsteps.

148. To increase stealth, submariners take advantage of how sound waves act in ocean water. The speed of sound in seawater is greatly determined by temperature, pressure, and salinity. These three factors vary in different locations and bend the sound waves accordingly. Because sonar depends on receiving sounds signals, the way sound waves bend determines what can be picked up by sonar. Submariners can find places between the bending sound waves of active enemy sonar called shadow zones. There, subs can hide and watch the enemy without being detected.

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[82] www.history.navy.mil

149. Silencing the Submarine.[83]

(a) Air Independent Propulsion (AIP) System. The AIP system of the submarine should comprise the virtually vibration-free and silent engine. The fact that the submarine can operate at great depths for long periods of time is also an important stealth factor.

(b) Hull. The hydrodynamic design of the hull, rudder and propeller is of vital importance. The flow sound when the submarine travels through the water can disturb the submarine's own hydrophones and can also be heard by the enemy.

(c) Sonar Avoidance. Active sonar is a serious threat. The main factors in avoiding detection are the geometry of the hull, fin and control surfaces, and the materials used. An anechoic coating has a major effect on the avoidance of detection.

(d) Countering the Magnetic Field. A vessel travelling on the surface or under water gives rise to detectable local disturbances in the Earth's magnetic field. This can be avoided by demagnetizing the ship by generating a counteracting magnetic field.

(e) ELF Signature. Galvanic currents flowing in the hull and in the water around the hull generate underwater electrical potentials. Under certain conditions, this can cause extremely low frequency (ELF) electrical fields to be radiated into the water. Detection of the ELF signature can be prevented by short circuiting the electrical current by earthing.

(f) Wake Phenomenon. When a submarine travels on the surface or at periscope depth, variations in the pressure field, vortices and the wake are detectable. When submerged just below the surface, the submarine can generate detectable surface waves and water velocity changes. The temperature of the surface water will be altered by the wake, and this can also be detected by IR sensors or radar. A hydrodynamic design will help keep signatures to a minimum.

(g) Avoiding Incident Radar Waves. The head of a submarine mast must have the smallest possible geometrical size. If a snort head is used, it should be equipped with a fairing provided with facets at different angles in order to reflect the incident waves away from the radar source. The masthead surface can also be covered with radar absorbing material to reduce the target strength even further.

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[83] www.sesusa.org

Figure 87

The Virginia (SSN 774) submarine is an advanced stealth multi-mission nuclear powered submarine for anti-submarine warfare and littoral operations. To achieve this low acoustic signature, the Virginia incorporates newly designed anechoic coatings, isolated deck structures and a new design of propulsor.

Figure 86

The Royal Navy's Astute Class submarine is a nuclear-powered attack submarine.

The Astute, the first attack submarine to be built in almost two decades, is the "most stealthy in the world" - (Daily Telegraph).

Application of Stealth Technology to Armoured Fighting Vehicles (AFVs)

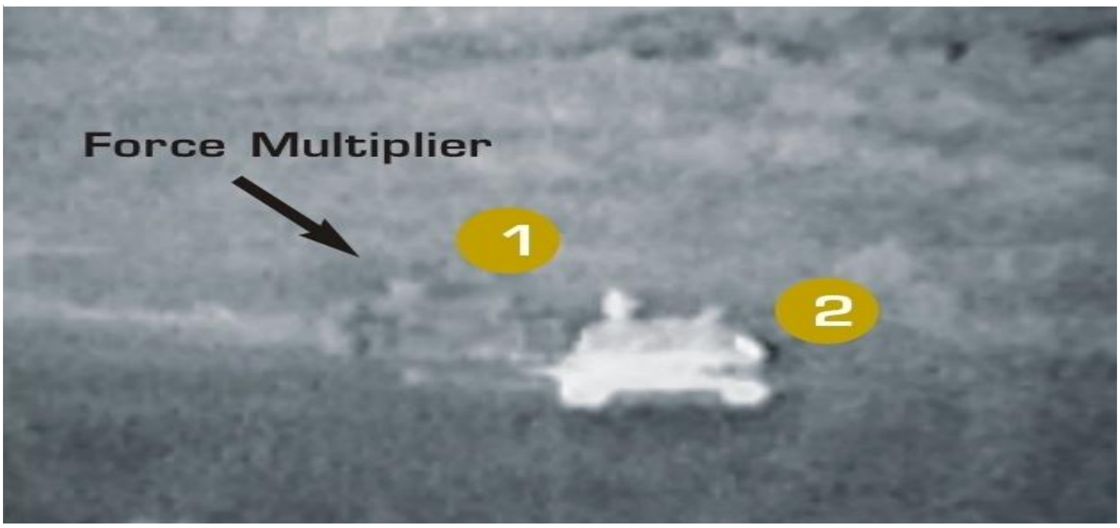
150. The application of this technology is most complicated when applied to mobile fighting land systems. This is because the entire spectrum of signature management is simultaneously applied.

151. Compounding the problem are the relative slow speeds involved, the highly dense tactical battlefield environment and the complexity offered by the terrain.

152. Stealth, when applied to AFVs cannot be viewed in isolation and may have to be a complete amalgamation of all the technologies whole of reduction in RCS (like the attempts in the Challenger), or reduction in noise by the running gear (similar to the attempts in the Leopard), the advent of the Plastic Tank which will no doubt have much reduces signatures, reduction of thermal signatures (being researched on worldwide), the use of RAMs, Composites etc. With all this; the biggest threat of visual recognition still remains the most potent threat. Therefore concepts like active camouflage, cloaking technologies etc come into play. Will AFVs have retracting weaponry to reduce their RCS? I am not even touching the complexities of the electronic spectrum.

153. Reservations apart there is definite a scope to explore this possibility but immediate application of signature management to AFVs is likely to be more compartmentalised as is presently the case. The present threat analysis reflecting a necessity to urgently manage IR signatures; this is likely to remain the focus of research. Compartmentalised application like use of RAMs, reduction of RCS will continue in the backdrop etc. and will assist increase the survivability of the AFVs. Indicators reveal that research on thermal signature management, cloaking and active camouflage are the directions of current research.

Figure 88



CONCLUSION

154. Technology is fast evolving. For every development in signature management and camouflage, detection measures seem to take it another notch up. The cat and mouse game will continue but the main fallout is the hindrance to academicians to be able to study ongoing research as all of these are highly classified (as can be justifiably understood).

155. To be able to truly have an insight as to where technology might be headed; not only does one need to be well read about the emerging technologies and their application but one should also have an active imagination (with sound scientific knowledge) to be able to realise these. Many of the applications discussed will also be applied to the field of deception.

156. Each emerging technology while providing a solution to one problem also highlights another set of new problems. Even the modern stealth aircraft have limitations in banking etc. This implies that technology aside; to truly be able to apply them for the designed conditions requires the discipline, prudence and imagination of the user. Nanotechnology looks set to take cutting edge technology to whole new dimensions affording a host of possibilities to be applied to both detection and camouflage measures.

157. Aspects related to signatures due to communications, power sources etc. though not having been covered here are also related to the application of these technologies and must also therefore be clearly understood for correct application.

158. Modern camouflage techniques have already be taken a multispectral approach. The use of artificial intelligence, smart environment adjusters etc. simplify judgement decisions but will come with their own limitations of power requirements, predictable responses etc. These will have to be amalgamated with the human factor, where the element of irrationality has on numerous occasions in the past assisted successful campaigning.

"When you have eliminated the impossible, whatever remains, however improbable, must be the truth"
– Sherlock Holmes

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